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CIVIL AND MILITARY SATELLITE COMMUNICATIONS

A systems overview and the future developments

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ABSTRACT

The project A90KM616, "Orientatie SATCOM", is being performed on behalf of the Royal Netherlands Navy (RNLN) to assist the Navy on the subject of satellite communications. This report is the result of the first phase of this study. The goal of the report is to give an overview of the phenomenon satellite-communication.

The result of the study is a general overview of satellite communications for both civil and military applications. Some examples of applications are; international telephony, television broadcasting, small private business networks, and mobile (at the moment still principally maritime) communications. In these applications satellite communication systems provide a global coverage and a high flexibility.

The scientific articles have not been considered because in this stage it was not the intention to study on a specialist level the broad area of techniques. Magazines, books and a number of reports of universities and research institutes have been the main sources of information. They provided afforded an understanding of the existing systems and insight in the future developments.

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SAMENVATTING

Het project A90KM616, "Orientatie SATCOM", wordt in opdracht van de Koninklijke Marine (KM) uitgevoerd om de marine bij te staan op het gebied van satelliet-communicatie. Dit rapport is het resultaat van de eerste fase van deze studie, waarin het de bedoeling was om een overzicht te krijgen van het fenomeen satelliet-communicatie.

Het studieresultaat is een algemeen overzicht van satelliet-communicatie voor zowel civiele als militaire toepassingen. Voorbeelden van toepassingen zijn; internationale telefoonverbindingen, televisie-uitzendingen, kleine privé-netwerken voor zakelijk verkeer, en mobiele (heden nog vnl. maritieme) communicatie. In deze toepassingen bieden satelliet-communicatiesystemen een grote flexibiliteit en communicatie over de hele wereld.

De wetenschappelijke artikelen zijn buiten beschouwing gelaten omdat het in dit stadium niet de bedoeling was om op specialistisch niveau het brede scala van gebruikte technieken te bestuderen. Tijdschriften, boeken en een aantal rapporten van universiteiten en onderzoeksinstituten zijn de voornaamste bronnen van informatie geweest. Zij gaven inzicht in de bestaande systemen en de te verwachten ontwikkelingen.

1 INTRODUCTION

The Royal Netherlands Navy (RNLN) is procuring fifteen ship-borne satellite communication earth stations. These ship-borne terminals will form a satellite communication network together with a NATO satellite and a large ground station in Schoonhoven, the Netherlands. This system will improve and complement the long distance communications (mainly provided by HF-communications) between the ships and the shore (Schoonhoven) and between ships. The network implementation will introduce network control and management aspects and possible EMI effects due to the large amount of electronic equipment using electromagnetic waves causing mutual interference. In addition, the satellite communication (SATCOM) installation must be designed to be reliable in rough circumstances and in periods of tension and war.

In order to be able to produce technical solutions to the implementation aspects, the RNLN committed the Physics and Electronics Laboratory (FEL) with a study on satellite communication to gain more knowledge about this field of interest. The study consists of two phases. The first phase is a literature study, of which the main goal is to get an overview of the satellite communication community, the users and the applications, and future developments. The second phase consists of the identification of the implementation aspects.

The first phase of the study will be finished by two reports. This report is the first one. It gives a general overview of the techniques that are employed, the existing communication satellites, the most well-known civil systems, the military systems, and the future developments in techniques, technologies and applications. A second, confidential, report will follow concerning the military operational aspects on satellite communications.

2 HISTORY OF SATCOM

Why is satellite communication so important? The two main reasons are the large coverage area and the flexibility that it provides [1]. Systems using a single satellite offer the flexibility to interconnect any pair of users separated by great distances up to approximately one-third of the circumference of the earth. Systems using three satellites can provide a global coverage with multiple-access flexibility, including communication links between satellites and fixed points on earth, ships at sea, airplanes, other moving vehicles, and man-pack terminals. Satellite communication costs are essentially insensitive to the distances between terminals. Another strong point of satellites lies in the fact that they can handle a large amount of traffic, although this benefit is provided by terrestrial microwave links and optical fibre links as well.

The theoretical possibility of placing three satellites in a geostationary orbit was proposed by Arthur C. Clarke, also known as a science-fiction author, in his article "Extra-terrestrial Relays", Wireless World, October 1945. After this proposal it lasted for eighteen years before the first geostationary satellite was placed in orbit. The global coverage that three satellites can provide is shown in Fig. 2.1. Note the "shadow" areas in the polar regions, which can be covered by satellites in specific orbits as will be discussed in chapter 2.

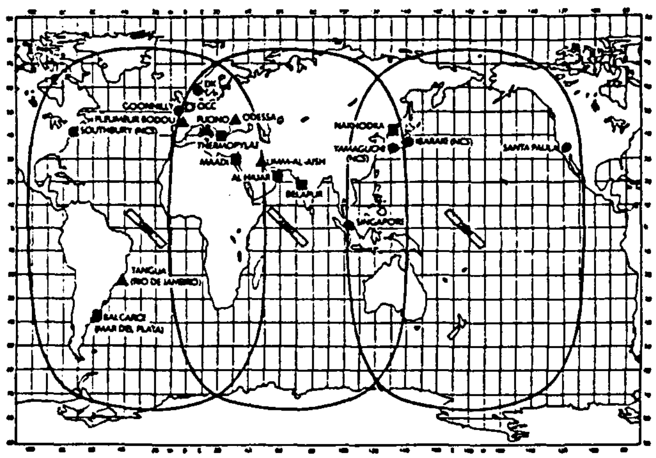


Fig. 2.1: Global coverage provided by the Inmarsat system [2]

The first space communications activity can be traced back to 1946 when the U.S. Army achieved radar contact with the moon. In 1954 the U.S. Navy began communications experiments using the moon as a passive reflector. In this way an operational communication link was established between Hawaii and Washington D.C. [3] by 1959.

2.1 SCORE

The first man-made communication satellite, Project SCORE, was launched in December 1958. The primary purpose of the project was to demonstrate that an Atlas missile could be put into orbit. Demonstration of a communications repeater was the secondary goal. The life time of this satellite was twelve days of which about eight hours were actual operation, after which the batteries failed. The SCORE communication subsystem is shown in Fig. 2.2.

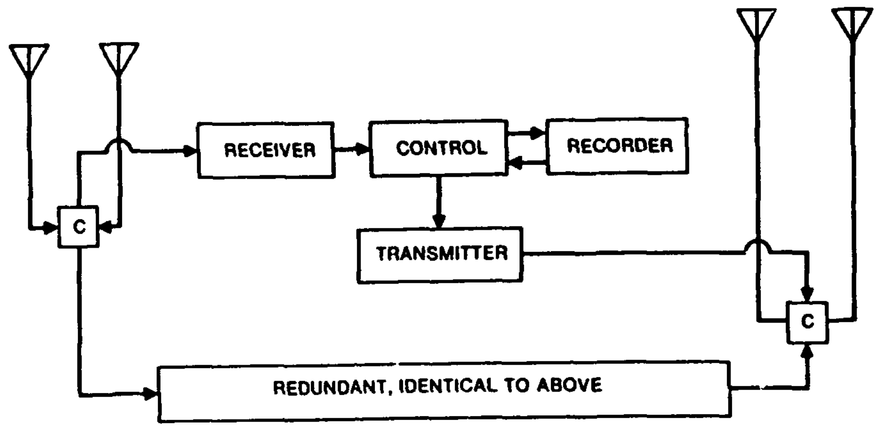


Fig. 2.2: SCORE Communication Subsystem [3]

Any of the four ground stations in the southern U.S. could command the satellite into a playback mode to transmit the stored message or into a record mode to receive and store a new message (Fig. 2.2). A real-time mode was also available in which the recorder was bypassed. One of the recorded signals was a Christmas message of President Eisenhower.

2.2 ECHO

During the late 1950s and early 1960s, the relative merits of passive and active communication satellites were often discussed. At the time of Project Echo, the main advantages given for passive satellites were: very wide bandwidths, multiple access capability, and no chance for degradations due to failures of satellite electronics. The disadvantages were: the lack of signal amplification, the relatively large orbit perturbations resulting from solar and atmospheric effects (because of the large surface-to-weight ratio), and the difficulty in maintaining the proper reflector shape. The use of active satellites soon overshadowed the passive satellites.

Project ECHO produced two passive satellites. Echo 1 was a sphere with a 100 ft diameter, whereas echo 2 was even larger with a diameter of 135 ft. They were launched in 1960 and 1964. Echo 1 was used for picture, data, and voice transmissions between a number of ground terminals in the United States and also for radar and optical measurements. Echo 2 was used primarily in scientific investigations similar to those performed with Echo 1 and very little for communications purposes.

2.3 SYNCOM 3

After the launch of some other experimental satellites (Courier, West Ford, Telstar and Relay) the system planners wanted to place a satellite in geostationary orbit. The National Aeronautics and Space Administration (NASA) conducted experiments at synchronous altitude using the Syncom satellites. Of these satellites Syncom 3 was the first satellite to be placed in geostationary orbit [4], which means that the satellite remains above a fixed geographical position on earth. The channelization consisted of two 500-kHz channels for narrowband two-way communications and one 5-MHz channel for one-way wideband transmissions. The wide-band channel was used to transmit the Tokyo Olympic games in the fall of 1964.

2.4 Experimental satellites

Because the private industry cannot support the higher risk, higher potential developments which require about a decade to bring them to commercial usefulness, there is a continuous need for government funded experimental satellites. As a result of the development and launch of these satellites a lot of progress has been made during the twenty years after the launch of Syncom 3. For these reasons NASA (US) was able to start their most recent project, developing the Advanced Communications Technology Satellite (ACTS).

The ACTS program objective is to develop and flight qualify high-risk technologies and techniques for the next generation of commercial communications satellites [5]. This satellite is not a simple repeater, but it contains a modem and a baseband processor able to sort, store, and route messages. ACTS uses the Ka band, 30- GHz uplink and 20-GHz downlink transmission. To combat fading at Ka-band frequencies, fade-countermeasures like adaptive coding and power control techniques are used. It interconnects different areas on earth by means of three antenna spot beams and a 3 x 3 switching matrix. The use of spot beams allows the use of very small ground stations with antennas of 1.2 to 1.8 metre in diameter.

In this context reference is made to the recent direct broadcasting satellites above Europe, which allow TV-reception with dishes of only 60 centimetres. This compares with the groundstations of 30 metres that were used for the television broadcasts through the Intelsat-1 satellite, launched in 1965, this being the first one commercially used [6]. It is worth mentioning that the Intelsat A station is still this large because it supports the current international trunk circuits, which carry

large bandwidth source signals. In the following chapter it will be explained why the transmission of large bandwidth source signals requires such a large antenna.

In Europe and Japan programs similar to ACTS are carried out. The European Space Agency (ESA) has launched succesfully the experimental satellite OLYMPUS in 1989 while the National Space Development Agency of Japan (NASDA) will launch its largest experimental satellite (ETS-VI) in mid-1992 [9].

2.5 Growth of satellite communications

A lot of examples could be elaborated here to show the progress of satellite communication during the last 25 years. However, the reader is invited to compare the satellite systems of this moment, described in chapter three, with the first geostationary satellite Syncom 3, launched in 1964. But not only the satellite systems themselves have grown in there number, size and complexity, also a lot of satellite organisations have been founded.

An important organisation is the National Aeronautics and Space Administration (NASA), which is an Agency of the US Government. It has a significant role in all aspects of space exploration and research. Its counterpart in Europe is the European Space Agency (ESA). ESA is engaged not only in space research, but also in the operation of communications and broadcasting satellites. Intelsat (the International Telecommunications Satellite Organization) is the oldest communications satellite organisation, existing already for more than 25 years. Fig. 2.3 on the next page shows the growth of the number of Intelsat groundstations during the years. Inmarsat (International Maritime Satellite Organisation) is an organisation similar to Intelsat, but concentrates on communications to ships, offshore oil platforms, and quite recently extended its area of interest to land and air mobile communications.

Other organisations are the military organisations like the US Department of Defense (DoD) and the North Atlantic Treaty Organisation (NATO). They support the procurement and development of their own satellite systems because military satellite systems are to be survivable under threat, in which they differ from civil systems.

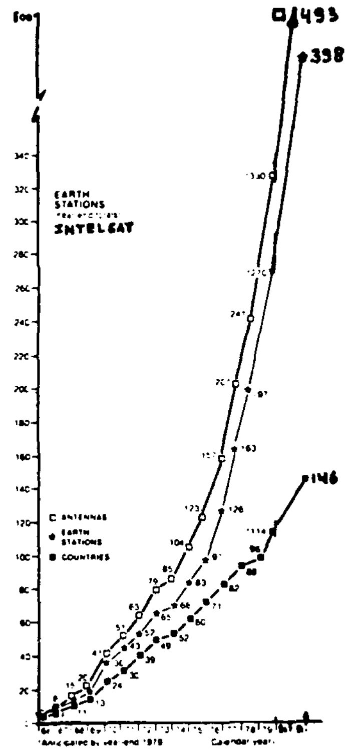
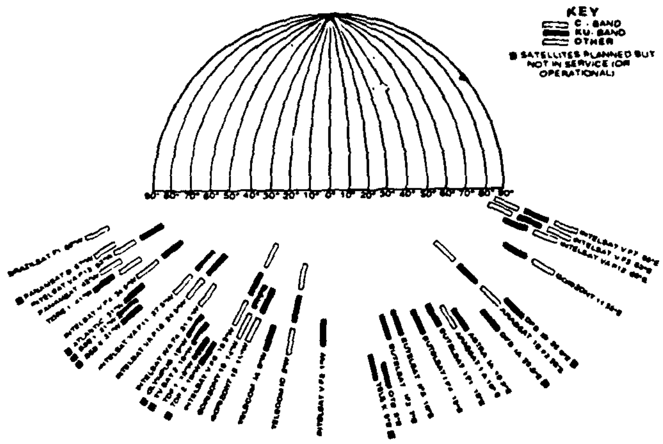


Fig. 2.3: Growth of the number of Intelsat ground stations over the past years [7]

Next to these large organisations, a lot of regional and domestic systems have evolved to meet specific regional and national demands. To illustrate the number of communications satellites, Fig. 2.4 and 2.4a [8] on the next two pages are included. It shows the current occupation of the geostationary orbit by communications satellites, together with a brief description of them.



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66°E:
Intelsat V F7 acts as reserve satellite for the Indian Ocean Region of Intelsat's global system. But far from being 'spare', the satellite provides capacity for many of the region's domestic and international leased telecommunications services in the region. These include C-band TV services for China (three channels), for Zaire and Ethiopia, and for the US Information Agency's WorldNet channel. Iran, Turkey and American forces TV share the Ku-band capacity.

63°E:
Intelsat V F5 occupies the Indian Ocean Major Path telecommunications slot, linking secondary antennas at major earth stations in the region. C-band domestic services include South Africa and Algeria, and Ku-band transponders are available for occasional TV circuits to and from the Far East.

60°E:
Intelsat VA F12 is the Indian Ocean Primary, and carries the bulk of Intelsat telephony traffic between Europe and Asia, at C-band. At 11 GHz six West German Pal TV services are downlinked to Europe in half-transponder format. The Eins Plus channel (11.550 GHz, horizontal) is used by the Bundespost for daytime D2 Mac test transmissions. AFRTS (US forces TV) uses 525-line B Mac coding for programme distribution to US bases in the Federal Republic.

53°E:
Gorizont 11 relays the first and second programmes of Soviet Central TV via 4 GHz downlinks.

30°E:
This is the slot used for on-orbit testing of new Intelsat spacecraft, in conjunction with the Italian earth station at Fucino. The newly-launched Intelsat VB, F15, was observed under test here during February.

26°E:
Arabsat-1B (F2) provides telecommunications services to Arab League member nations via 25 C-band transponders. News exchanges are frequent, but Saudi Arabia (2 channels) and Oman operate the only full-time TV services on the satellite.

19.2°E:
Astra 1A. January 23 saw the first TV transmissions on Astra-1A, only two weeks before the launch of Sky Television, and a live transmission was featured in the BBC programme Tomorrow's World on January 24. FilmNet was first up with full programme service on February 1, with four of Sky's six channels following on February 5. Since then they have been joined by TV3 ScanSat in D2 Mac and MTV Europe in Pal. Promotional transmissions from the Astra control station at Betzdorf are carried in Transponders 10 and 14 (V2 beam), and give up-to-date information on channel occupancy. This makes a total of nine transponders up and running at mid-February. Signal strength in the UK is generally as expected, with the V1 beam (Vertical Mode 1) delivering the strongest signals and V2 the weakest, a spread of about 1.5dB at the C&SEu lab in Gloucestershire. Even the weakest channel delivers some 12.5dB clear sky carrier to noise ratio here, into a standard low cost 60cm consumer terminal; the strongest channels show a healthy 6dB margin above receiver threshold. Reports from other parts of Europe, particularly Spain, suggest that not everyone is so happy with Astra's signal levels, although SES declares performance to be as predicted. The discrepancy may be due in part to the trade's undue dependence on the four published footprint maps, each an average of four different

Fig. 2.4: Civil satellites in geostationary orbits

channel programme, plus a temptation to underestimate the rate of decline in signal level of the shaped beams outside the published 44dBW contour.

19°E:

Arabsat 1A (F1) acts as an on-orbit spare, transmitting only telemetry beacon signals at present.

16°E:

Eutelsat IF1 still has no regular TV service since moving to its new location. BTI test transmissions for the BBC were observed in Transponder 10 in late January.

13°E:

Eutelsat IF4. Ten transponders are in use for some thirteen programme services across three downlink beams. With Sky Television's relaunch, Sky Channel's cable viewers, with no access to Astra, were surprised to find their expected evening programmes on Transponder 6 replaced by Eurosport material.

10°E:

Eutelsat I F5. TV services in clear Pal from RAI (Italy, two channels) and TVE (Spain). NRK (Norway) uses C Mac, and the French transponder (10) carries B Mac test transmissions. TVE has also been seen testing in the Spot Atlantic beam.

7°E:

Eutelsat IF2. The IBA's D Mac packet test transmissions for BSB receiver manufacturers continue each morning at 11.639 GHz in Transponder 6. The channel reverts to its alternative frequency of 11.676 GHz for other occasional TV traffic, including ITN World News in Pal at 18.35 hours GMT.

1°W:

Intelsat V F2. The Ku-band West spot beam, boresighted on southern Scandinavia, is used by the Norwegian Televerket for relay of Sweden's two TV services (in scrambled C Mac) plus two Norwegian independent TV channels in Pal, all in half-transponder format. Israel TV transmits two channels via the East spot beam, suitably repointed to Israel. At C-band the global AFRTS feed continues in clear NTSC, though the anticipated switch to B Mac encryption is reported to be close at hand. Gabon and Niger TV also occupy 4 GHz downlink channels.

5°W:

Télécom 1C beams three full-time TV services, la Cinq, M6 and Canal J, to France in the 12.5 GHz band. The three spare channels carry a variety of test cards and videoconference feeds, and are all heavily loaded with subcarrier radio services.

8°W:

Télécom 1A provides back-up capacity in the French Télécom 1 system.

11°W:

Gorizont 12 augments the 4 GHz TV distributor service provided by its neighbour Gorizont 15, as part of the USSR's global geostationary satellite network. Moscow TV's second channel is now transmitted full time at 3875 MHz in Secam, using a Northern Hemispheric beam pattern.

14°W:

Gorizont 15, in the Statsionar-4 slot, is the Soviet Union's primary Atlantic satellite, and transmits Soviet Central Television's Channel One into Eastern Europe at 3.675 GHz. Global-pattern beams are used for programme exchange among Intervision and Intersputnik member nations.

18.5°W:

Intelsat V F6, Major Path 2. Four half-transponder channels in the Ku-band East spot beam of this satellite are in daily use by Italian independent broadcasters (notably Canale 5) for programme distribution in Pal.

19°W:

In TDF1 the French have a satellite with high power five-channel capacity similar to the UK's planned BSB, but with little interest from programmers. The first full-time TV service is France's cultural seventh network la Sept, which began transmissions in February, using the D2 Mac test and demonstration material. Signal levels are quite adequate for a 30cm dish in southern England and over all of France.

21.5°W:

Intelsat IVA F4. From a highly-inclined orbit this 11-year-old satellite is now used only by Sudan for internal TV and radio programme distribution, plus SCPC telephony, at 4 GHz. The Intelsat IVA satellites are not equipped for Ku-band.

24.5°W:

The Atlantic Primary (Intelsat VA F10) is dedicated to full-time transatlantic telecommunications service, and carries no Ku-band television.

27.5°W:

Intelsat VA F11. The Atlantic Ocean Region also has its reserve, and this one too has been kept busy with leased transponder TV services. The UK has made good use of the Ku-band spot beams, through BTI's efforts from as far back as 1983 when the slot was occupied by Intelsat V F4. Now changes are afoot, with some of the UK 'cable' programmers shifting to Astra and new ones taking their places — already The Discovery Channel is planning to launch in April. Currently six UK channels, one Dutch (Kindernet) and one US (CNN) use the satellite's Ku-band payload. CNN Europe is uplinked direct from Atlanta, Georgia at 6 GHz, and cross-strapped on board the satellite to the Ku-band spot East beam. The same technique is used for the EBU's half-transponder feed from New York and Washington. Additionally, a remarkable total of 17 TV contribution and distribution services operate through the satellite's 4 GHz downlinks, on both sides of the Atlantic.

34.5°W:

Intelsat V F4, Atlantic Major Path 1. In addition to international telephony and occasional TV traffic, both of the Spanish national (TVE) channels are transmitted full-time to the Canary Islands via a C-band Zone beam transponder.

45°W:

PanAmSat F1 (Simon Bolivar) carries the GalaVision feed into the UK on its transatlantic hop. Other transponders are in reserve for occasional transatlantic TV circuits at Ku-band.

53°W:

Intelsat's IBS satellite (VA F13) supports transatlantic digital business traffic at Ku-band. C-band TV users include Portugal and Morocco, plus a number of South American nations.

Fig. 2.4a: Continuation of Fig. 2.4

2.6 References

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3 THE SATELLITE COMMUNICATIONS LINK

In this chapter the key elements of a point to point satellite communications link will be discussed. The following three sections will discuss the transmitting and receiving antenna gain, the power received by an antenna and the signal to noise ratio on a satellite communications link. These sections will be the basic for the fourth section on linkbudget calculations, which gives the basic for the engineering of earth stations given a certain satellite. The last section of this chapter will discuss the signal processing techniques needed to change the original source signal to a radio frequency signal suited for transmission to and from the satellite.

3.1 Antenna gain

One of the most essential components of communication satellites and earth stations is the antenna. This antenna often consists of a feed system, which transforms the electric communications signals into an electromagnetic wave, and a reflector dish, which directs the electromagnetic waves on the path between the earth stations and the satellite. This directivity of the reflector avoids the waste of electromagnetic power, as the path from earth station to the geostationary communication satellite is approximately 36.000 km and causes a power loss that is around 200 dB.

The gain of an antenna, which in fact is a measure of the directivity, is defined with respect to the gain of an isotropic antenna. An isotropic transmitting antenna radiates a spherical wave with a uniform power $p_o/4\pi$ in any direction of the surrounding space (p_o being the power available at the input of the antenna). A reflector antenna (Fig.3.1, next page) will radiate to a receiver a power which depends on the angle (θ) between the straight path from transmitting antenna to the receiver and the axis of the reflector dish (Fig. 3.2 and 3.3 on the next pages). Fig. 3.2 shows theoretical pattern and the so called main lobe and side lobes, while Fig. 3.3 shows the actually measured radiation pattern of a reflector dish antenna as a function of θ.

The antenna gain g (or G if it is expressed in decibels) is maximum on the axis of the dish and defined as the ratio of the maximum gain and the isotropic gain.

$$g = \frac{p_{max}}{p_o/4\pi} \qquad (1)$$

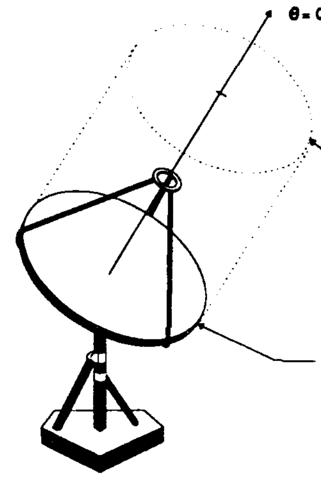


Fig. 3.1: Earth station antenna

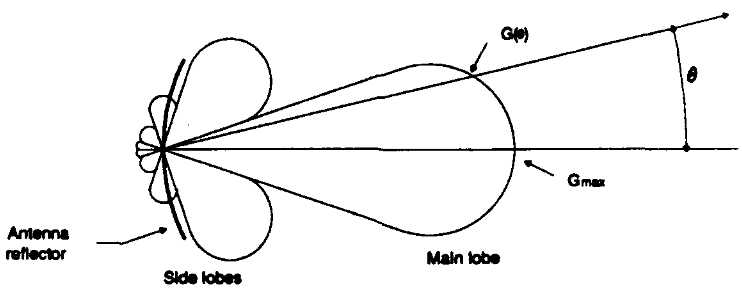


Fig. 3.2: Antenna radiation pattern, main lobe and side lobes

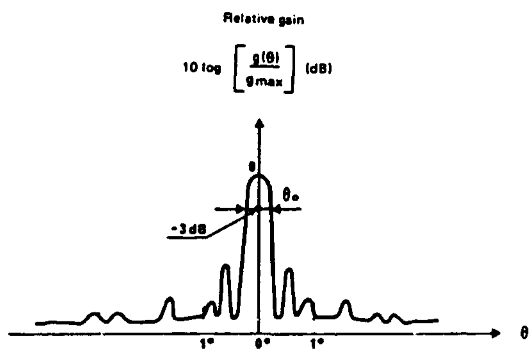


Fig. 3.3: Antenna radiation as a function of θ

The maximum gain, often referred to as antenna gain g, is usually expressed in decibels (dBi, i.e. dB over isotropic, the isotropic gain is 0 dBi). A very important relation between the gain, the wavelength λ (in metres), the antenna efficiency η, and the projected aperture area A (in square metres, shown in Fig. 3.1) of the reflector dish is:

$$g_{max} = \frac{4\pi\eta A}{\lambda^2} \qquad (2)$$

where $\lambda = c/f$, c is the RF waves velocity = 3×10^8 (m/s) and f is the radio frequency (Hz).

If the antenna would be perfect and lossless, the antenna efficiency η would be equal to 1, but due to losses and the non-uniformity of the illumination of the reflector by the feed system practical values of η are between 0.6 and 0.8. ηA is called the "effective area" of the antenna.

For a circular aperture with diameter D ($A = \pi D^2/4$) the gain function, expressed in dB, would be

$$G = 10 \log g_{max} = 9.94 + 10 \log \eta + 20 \log (D/\lambda) \text{ dBi.} \qquad (3)$$

From the equations above it will be clear that the antenna gain is proportional to the aperture area of the reflector and the square of the radio frequency. A typical antenna radiation diagram has

already been depicted in Fig. 3.3, which shows the half power beamwidth θ_0 and the antenna gain as function of the angle θ at a fixed frequency.

3.2 Transmitted and received power by an antenna

If p_e (e stands for exciter) is the power that is supplied to the antenna and g_e is the antenna gain in a given direction, then the product $p_e \cdot g_e$ is called the equivalent isotropically radiated power in that direction, or e.i.r.p. (often also abbreviated as EIRP). If it is expressed in decibels, the unit is dBW (P_e in dBW + G_e in dBi). The e.i.r.p. is often one of the important characteristic values in specifying a satellite or earth station. The power flux-density (pfd), i.e. the power radiated by the antenna in a given direction at a sufficiently large distance d per unit of surface area, can be written as a function of the e.i.r.p.:

$$(pfd) = e.i.r.p./(4\pi d^2) \qquad (4)$$

Combining (2) and (4), the power that is received by an antenna can now be defined as

$$p_r = (pfd)\cdot\eta A = p_e \cdot g_e \cdot g_r \left(\frac{\lambda}{4\pi d}\right)^2, \qquad (5)$$

where r stands for receiver.

From formula (5) it can be concluded that the received power is determined by the excited power and the antenna gain at the transmitter, the antenna gain of the receiver, and a term of which the reciproke represents the free-space loss between isotropic antennas. This term is defined as

$$l = (4\pi d/\lambda)^2, \qquad (6)$$

or in decibels as

$$L = 20 \log (4\pi d/\lambda). \qquad (7)$$

At a frequency of 6 GHz and a distance of 36.000 km this attenuation is 200 dB.

The received power will actually be less than calculated with formula (5), because as well as losses due to free-space attenuation other losses must be taken into account. Additional losses are:

- Losses due to polarization mismatch of the electromagnetic wave at the antenna interface and to cross-polarization caused by propagation (the electrical component of the incoming electromagnetic wave will then consist not only of an electrical, but of a magnetic component as well, and the same applies to the magnetic component the other way round).

- Losses due to antenna offset with respect to the nominal direction commonly referred to as pointing error losses. The degradation to the antenna gain ΔG as a function of the off-boresight angle $\Delta\theta$ is

  $$\Delta G = 12\,(\Delta\theta/\theta_o)^2 \quad \text{dB.} \qquad (8)/$$

  The half power beamwidth θ_o can be calculated with the following formula:

  $$\theta_o = 65\,\lambda/D. \qquad (9)$$

- Feeder losses, generally included in the e.i.r.p. on emission and in the station sensitivity on reception.

- Atmospheric losses representing the losses due to propagation in the atmosphere and the ionosphere.

The atmospheric losses need some further explanation here, because they can be very significant. The actual atmospheric losses are very dependent on the expected rain fall in the communication area and the frequency band. For frequencies up to 10 GHz the losses are smaller than one dB, but at frequencies of e.g. 30 GHz the losses may be several tens of decibels. The influence of rain-induced atmospheric attenuation as a function of the frequency is depicted in Fig. 3.4 [1].

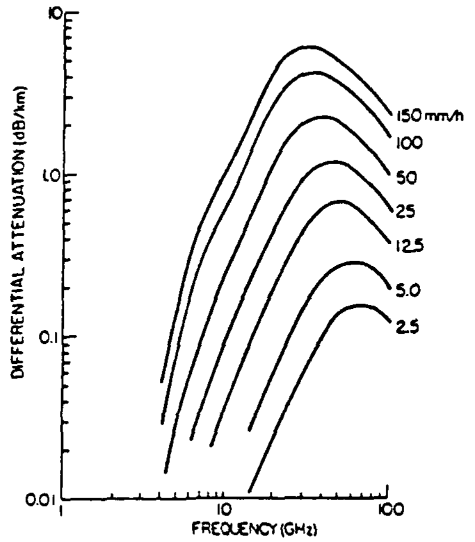


Fig. 3.4: Rain-induced attenuation

As well as the rain-induced attenuation an extra atmospheric path loss due to atmospheric gasses has to be accounted for. This attenuation is also frequency dependent and is shown in Fig. 3.5 [1]. As one can see, this extra path loss is neglectable in respect to that caused by rain fall. At very high frequencies however (higher than 50 GHz) the attenuation is large and has a specific maximum at 60 GHz. This can turn to an advantage however for military intersatellite communications links (see section 7.3.3) at 60 GHz, which cannot be detected or disturbed by an enemy from earth.

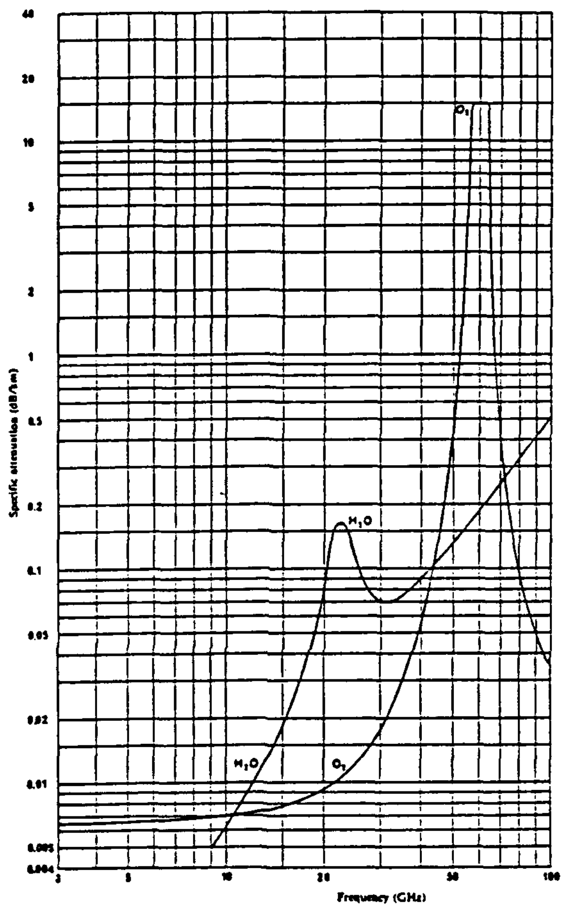


Fig. 3.5: Specific attenuation due to atmospheric gases under the following conditions

Pressure	: 1 atm
Temperature	: 300 K
Water vapor	: 7.5 g/m^3

3.3 Signal to noise ratio and figure of merit

The signal to noise ratio is a very important measure, since its value determines the quality of reception. To obtain the signal to noise ratio, the received signal power and the received noise power have to be calculated. The received power can already be calculated with the knowledge obtained from the previous paragraph.

The received noise power is due to an internal noise source in the receiver and to an external source, the antenna contribution. In satellite communications link budget calculations (see the following section) usually the term noise power (N expressed in Watts) is not used, but the noise spectral density in W/Hz (No), or the noise temperature (T in absolute degrees Kelvin). This is to avoid the need for specifying the bandwidth B in which the noise is measured. The terms are related as:

$$N = kTB \quad \text{and} \quad N_o = N/B, \quad \text{so} \quad N_o = kT. \tag{10}$$

where k is Boltzmann's constant, 1.38 x 10^{-23} Joule/Kelvin (or -228.6 dB Joule/Kelvin). Now that the terms have been specified, the noise temperature of a receiving system will be calculated.

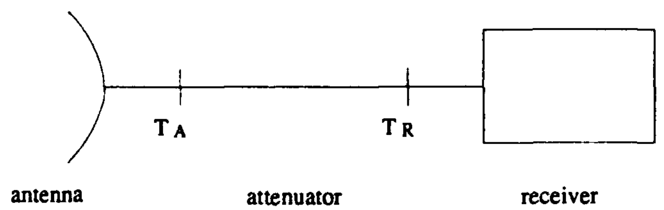


Fig. 3.6: Noise temperature of a receiving system

Fig. 3.6 shows a receiving system, which includes the antenna, the receiver, and the attenuation between antenna and receiver. The attenuation is caused by losses in the antenna, the feeder or the space between the signal source and the antenna. The noise temperature of this receiving system referred to the receiver input is

$$T_{RS(REC)} = T_R + T_a(1-1/a) + T_A/a \tag{11}$$

where $T_{RS(REC)}$ = temperature of the receiving system referred to the receiver input
T_R = temperature of the receiver
T_a = temperature of the attenuator
a = loss due to the attenuator
T_A = temperature of an antenna, equal to the sum of the external noise collected by the antenna

If the noise temperature is referred to the output of the antenna, it is equal to

$$T_{RS(ANT)} = T_A + (a-1)T_a + a \cdot T_R \tag{12}$$

Usually, in a carefully designed system, the losses are neglectable and "a" almost equals 1. Then the receiving system noise temperature can be written as

$$T_{RS} = T_A + T_R \tag{13}$$

3.3.1 Antenna noise temperature

The antenna noise temperature will be different for the satellite and the earth station.

The main lobe of a satellite antenna, which receives the main part of the total received power, is facing the earth (Fig.3.7). The noise from the radio stars, the sun, the moon and the other planets has a minor noise temperature of 6 K [2] and is only received by the antenna sidelobes. The terrestrial noise due to atmospheric attenuation and ground is therefore the dominant contribution to the total noise. The total noise power received by the satellite antenna is determined by the terrestrial noise which has a noise temperature of about 290 K.

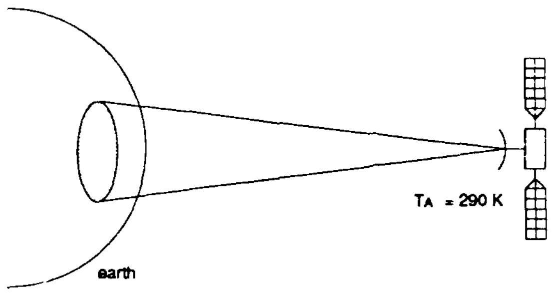


Fig. 3.7: Noise received by satellite antenna

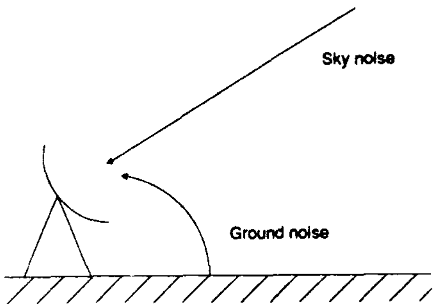


Fig. 3.8: Noise received by earth station antenna

An earth station antenna pointing straight upwards to the sky is facing the radio stars, the Sun, the Moon and the planets, so the received noise power should have a temperature of only 6K (Fig. 3.8). However, via the antenna sidelobes a small portion of the large terrestrial noise power will be received. This portion will be more significant if the elevation angle (the angle of the antenna disk axis with the ground plane) is less than 90 degrees. This situation will occur very often, because many earth stations will not be positioned on the equator. In Europe for example, the elevation angle is about 30 degrees. Depending on its radiation diagram, the antenna will collect ground noise via its sidelobes. The larger the antenna or frequency, the less noise will be collected this way because the antenna beamwidth will be smaller (formula (9)). Typical antenna noise

temperatures are 10 K for a large Cassegrain antenna [3, page 240] and 100 K for a small dish antenna.

3.3.2 Receiver noise temperature

The noise factor F of a receiving amplifier is given in its specifications and is a figure which is determined by the receiver noise and a reference temperature T_o (T_o = 290 K). The receiver noise temperature T_R can be calculated with the noise factor F of the receiver as follows:

$$T_R = T_o \cdot (F-1) \tag{14}$$

The noise factor is often provided in decibels, so it has first to be calculated in absolute values. Solid state gallium arsenide field effect transistor (FET) amplifiers with a noise factor of about 1.8 dB (1.51 in absolute values) at 12 GHz are already on the market. This gives the following receiver noise temperature:

$$T_R = 290\ \text{K} \cdot (1.51 - 1) = 150\ \text{K}.$$

This is a very satisfactorily value when such a receiver is combined with small dish antennas having an antenna temperature of about 100 K. For the large antennas with a temperature of only 10 K it would be a waste not to use cryogenic parametric low noise amplifiers with a noise temperature of about 15 K.

3.3.3 Figure of merit

The signal to noise ratio for reception depends on the received signal power and the noise temperature of the receiving system. This can be calculated with the formulas given in the previous paragraphs, but this is not always needed because often the transmitted e.i.r.p. and the figure of merit of the earth stations and the satellite are specified. The figure of merit is defined as the ratio between the gain of the receiving antenna in the direction of the received signal and the receiving system noise temperature defined by equation (12).

$$G/T = 10 \log g - 10 \log T_{RS(ANT)} \quad \text{dB/K}$$

The e.i.r.p. and figure of merit are key design parameters for transmitting and receiving systems of earth stations and for transmitting systems of satellites. The noise temperature of satellite

receivers is not that critical, because the antenna noise temperature is always about 290 K and therefore placing a very low noise amplifier in satellite receiving systems makes no sense.

Typical figures of merit for earth stations are: 41 dB/K at downlink frequencies of 4 GHz with earth station antennas of 30 m and a cooled parametric amplifier, 23 dB/K for an antenna of 4.5 meter in diameter and a FET-amplifier. For satellites the figure of merit ranges from -19 dB/K for an earth coverage antenna to 0 dB/K for a narrow spot beam antenna at uplink frequencies of 6 GHz.

3.4 Link budget calculations

Pertinent to an understanding of the critical aspects of a satellite communication link are the following link calculations, which will briefly be discussed and illustrated. The space link consists of the path from the earth station to the satellite, called the uplink, and the path from the satellite back to the earth station, called the downlink. The concept of a point to point satellite communications link is illustrated in Fig. 3.9. In this picture the following variables are depicted:

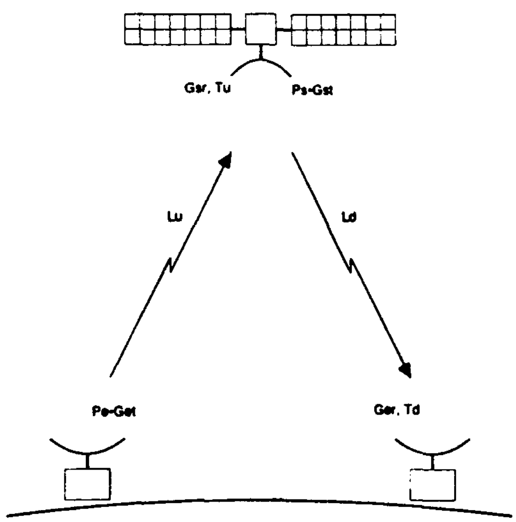


Fig. 3.9: Point to point satellite communications link

Pe : The transmitted power by the earth station.
Get : The antenna transmission gain of the earth station on the left.
Gsr : The antenna reception gain of the satellite antenna.
Gst : The antenna transmission gain of the satellite antenna.
Ger : The antenna reception gain of the earth station on the right.
Lu : The free space attenuation in the uplink.
Ld : The free space attenuation in the downlink.

In most cases the same antenna is used for transmission and reception. The transmitting and receiving frequencies are different and can be separated by the use of a diplexer feed in the antenna. The use of different frequencies for transmission and reception, while using the same antenna, causes a difference in transmission gain and reception gain.

3.4.1 The uplink equation

The uplink equation, which gives an expression for the carrier-to-noise spectral density c/N_o (C/N_o if expressed in decibels) on the path to the satellite, appears in the two forms below, depending on the perspective and available information. Where satellite receiver characteristics are given, the first one is used; where earth station transmit parameters are given (using the parameters of Fig. 3.9), the second one is convenient.

$$(c/N_o)_u = (pfd)_u \cdot (\lambda^2/4\pi) \cdot (g/T)_s / (k \cdot l_{r,u}) \qquad (15a)$$

$$(c/N_o)_u = (e.i.r.p.)_e \cdot (g/T)_s / (l_{p,u} \cdot k \cdot l_{r,u}) \qquad (15b)$$

where
u designates the uplink
s designates the satellite
$(pfd)_u$ = power flux density for the uplink
$(g/T)_s$ = figure of merit for satellite
k = Boltzmann's constant (1.380×10^{-23} J/K, or in decibels -228.6 dBW/K·Hz)
$l_{r,u}$ = uplink margin for rainfall attenuation
$(e.i.r.p.)_e$ = effective isotropic radiated transmitted power, Earth station
$l_{p,u}$ = free-space path loss, uplink

Note the uplink margin for rainfall attenuation. As explained in section 3.1.2 additional losses on the communications path can occur by rainfall. Therefore a margin is included in the link budget calculation to be sure that the received carrier-to-noise ratio will not be less than expected.

The carrier-to-noise density in decibels is expressed as follows:

$$(C/N_o)_u = 10 \log (c/N_o) = \varphi_s + A_{iso} - BO_i + (G/T)_s - k - L_{r,u} \quad \mathrm{dB{\cdot}Hz} \tag{16a}$$

$$(C/N_o)_u = 10 \log (c/N_o) = (e.i.r.p.)_e - L_{p,u} + (G/T)_s - k - L_{r,u} \quad \mathrm{dB{\cdot}Hz} \tag{16b}$$

where φ_s = flux density at Travelling Wave Tube Amplifier (TWTA) saturation, $\mathrm{dBW/m^2}$

A_{iso} = effective area of an isotropic antenna ($\lambda^2/4\pi$, to be derived from equation (2) with $g_{max} = 1$), $\mathrm{dB{\cdot}m^2}$;

BO_i = input backoff, dB

In (16a), the power flux density for the uplink $(pfd)_u$ is written as the flux density at TWTA saturation minus the input backoff: $10 \log (pfd)_u = \varphi_s - BO_i \quad \mathrm{dBW/m^2}$. This will be explained in the next paragraph. It must further be noted that $\lambda^2/4\pi$ is written as A_{iso}.

- The flux density at TWTA saturation: The amplifying element of a communications satellite output amplifier is a travelling wave tube [4]. If this amplifier is driven into saturation, intermodulation occurs which causes mutual channel interference. The flux density at TWTA saturation is therefore a limiting value for the e.i.r.p. of the transmitting earth stations. It is not usefull to build earth stations that are able to generate more than φ_s.
- The input backoff: this term is defined as the ratio of the single carrier saturation input power and the actual input power. This means that if the input backoff is 10 dB, $(pfd)_u$ is 10 dB less than φ_s.

When C/N_o is obtained from the link budget, the carrier-to-noise ratio (C/N) is readily calculated.

$$(C/N)_u = C/N_o)_u - B_s \quad dB \qquad (17)$$

where B_s is the receiver noise bandwidth at the satellite, dB·Hz.

The saturating flux density for the satellite and the e.i.r.p. for the earth station are key design parameters. E.i.r.p. does depend on the antenna gain; hence for a given available power P_e (transmitted power by earth station), the dependence is as f^2, since G_{et} (antenna transmission gain of earth station) is proportional to f^2. Also, for a fixed e.i.r.p., a trade-off between P_e and G_{et} can be made, subject to available power, pointing accuracies and reflector sizes. At a given frequency, this means that a larger reflector will reduce the required transmitter power.

Table 3.1 shows an uplink budget for $(C/N_o)_u$ under the conditions of saturation of the satellite TWTA and no rain attenuation, therefore the input backoff and the rain loss are both equal to 0 dB.

Table 3.1: Example of an Uplink Budget, frequency dependent terms are calculated for f_u = 6 GHz

Flux density at saturation	φ_s	-81.0	dBW/m²
Effective area of isotropic antenna	$+A_{iso}$	-37.0	dB·m²
Input backoff	$-BO_i$	-0.0	dB
Satellite figure of merit	$+(G/T)_s$	+0.0	dB/K
Boltzmann's constant	$-k$	+228.6	dBW/K·Hz
Rain loss, dry weather	$-L_{r,u}$	-0.0	dB
Carrier-to-noise density	$(C/N_0)_{u,s}$	110.6	dB·Hz

3.4.2 The downlink equation

The downlink equation is given below. It is written in decibels, similar to equation (16b).

$$(C/N_o)_d=(e.i.r.p.)_s-BO_o-L_{p,d}+(G/T)_e-k-L_{r,d} \quad \text{dB·Hz} \qquad (18)$$

where

d designates the downlink

e designates the earth station

$(e.i.r.p.)_s$ = e.i.r.p. by the satellite at TWTA saturation, dBW

BO_o = output backoff, dB

Other terms are defined in (15a,b) and (16a,b).

The output backoff is defined as the ratio of the single carrier saturation output power and the actual output power. In Fig. 3.10 the power transfer function of TWTAs is illustrated. It can be derived by inspection that the output backoff is a nonlinear function of the input backoff.

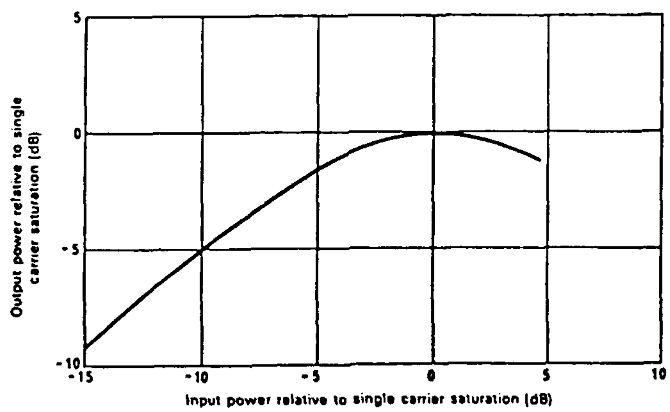


Fig. 3.10: Example of a characteristic curve for a TWT aboard a satellite

Table 3.2 illustrates a typical downlink budget. The output backoff is 0 dB, because the satellite is operated at saturating flux density (see uplink budget, table 3.1). Note that losses such as those due to pointing errors caused by pointing of antennas in static conditions, in tracking conditions and under wind loads are not included.

Table 3.2: Example of a Downlink Budget, $f_d = 4$ GHz

Satellite radiated power	$(e.i.r.p.)_s$	38.0	dBW
Output backoff	$-BO_o$	-0.0	dB
Free-space path loss	$-L_{p,d}$	-195.6	dB
Earth station figure of merit	$+(G/T)_e$	+21.0	dB/K
Boltzmann's constant	$-k$	+228.6	dBW/K·Hz
Rain loss, dry weather	$-L_{r,d}$	-0.0	dB
Carrier-to-noise density	$(C/N_o)_{d,s}$	92.0	dB·Hz

The numerical results of Table 3.1 and Table 3.2 are for a light traffic receiving earth station (antenna diameter is 4.5 metre) for use at 6/4 GHz with ANIK-D, a Canadian domestic satellite.

3.4.3 Total carrier-to-noise density

The total C/N_0 is given by

$$(C/N_o)_t = [(C/N_o)_u^{-1}+(C/N_o)_d^{-1}+(C/N_o)_{im}^{-1}]^{-1} \quad \text{dB·Hz} \qquad (7)$$

where $(C/N_o)_{im}$ is the contribution to the carrier-to-noise density that represents the intermodulation products caused by nonlinear operation of the satellite output amplifier. The addition must be made in numerical absolute values, not in dB. The optimum value of the input backoff, the output backoff and the intermodulation due to TWTA saturation, is determined by the maximum total C/N_o.

Assuming that the intermodulation and other noise are neglectable, the total carrier-to-noise spectral density ratio as derived from table 3.1 and 3.2 is

$$(C/N_o)_t = 91.94 \text{ dB·Hz}$$

As the downlink carrier-to-noise density (92.0 dB) is much lower than that for the uplink, this is the most determining factor to the total carrier-to-noise density in this case. It is illustrative for a broadcast from a large earth station to several smaller ones. In point to point links between earth stations similar to each other the uplink and downlink carrier-to-noise densities will not differ more than a few decibels.

From the carrier-to-noise density the available bandwidth can be derived for a required carrier-to-noise ratio in analog transmissions or, the available datarate in a datacommunications link for a required bit-to-noise density ratio. Lets assume a data communications link were an energy per bit-to-noise density ratio (E_b/N_o) of 10 dB is required for sufficient low bit error probability and a link margin of 1.94 dB is left for the account of atmospheric attenuation. Then the data rate in decibels is 91.94 - 10 - 1.94 dBbit/sec is available which corresponds to 100 Mbits/sec.

The transmitting earth station that is able to drive the satellite into saturation is a heavy traffic earth station with an available e.i.r.p. of 82 dBW (this station has a 30 meter dish antenna). If this station is called the large station, and the other station with the 4.5 meter antenna is called the small one, then the maximum data rate from large to small station is 100 Mbit/sec, not taking into account intermodulation and other noise.

3.4.4 Example of a link budget calculation

To provide the reader some more insight in link budgets, the link budget from the station with the 4.5 meter antenna (small) to the heavy traffic earth station (large) will now be calculated. The small earth station has an e.i.r.p. of 44.7 dBW and the large station has a figure of merit equal to 38 dB/K. Equation (15b) has been used to derive this uplink budget.

Table 3.3: The uplink budget, frequency dependent terms are calculated for f_u = 6 GHz

Earth station radiated power	$(e.i.r.p.)_e$	44.7	dBW
Free-space path loss	$-L_{p,u}$	-199.1	dB
Satellite figure of merit	$+(G/T)_s$	+0.0	dB/K
Boltzmann's constant	$-k$	+228.6	dBW/K·Hz
Rain loss, dry weather	$-L_{r,u}$	-0.0	dB
Carrier-to-noise density	$(C/N_o)_{u,s}$	74.2	dB·Hz

In table 3.1, the available power at the input of the satellite was -81.0 dBW - 37.0 dB = -118 dBW, the satellite was driven into saturation, so the input backoff was 0.0 dB. In table 3.3 the available power at the input of the satellite is 44.7 dBW - 199.1 dB = -154.4 dBW. The input backoff is thus -118 dBW - (-154.4 dBW) = 36.4 dB. The output backoff is not a linear function of the input backoff (Fig. 3.10), so lets assume that it is not 36.4 dB, but 5 dB less i.e. 31.4 dB. Now the downlink budget to the large earth station is:

Table 3.4: The downlink budget, f_d = 4 GHz

Satellite radiated power	$(e.i.r.p.)_s$	38.0	dBW
Output backoff	$-BO_o$	-31.4	dB
Free-space path loss	$-L_{p,d}$	-195.6	dB
Earth station figure of merit	$+(G/T)_e$	+38.0	dB/K
Boltzmann's constant	-k	+228.6	dBW/K·Hz
Rain loss, dry weather	$-L_{r,d}$	-0.0	dB
Carrier-to-noise density	$(C/N_o)_{d,s}$	77.6	dB·Hz

The downlink budget has a larger carrier-to-noise density than the uplink budget has (74.2 dB on the uplink and 77.6 dB on the downlink). Even if the antenna of the large station would be made larger to improve its figure of merit, this would not make much difference for the total carrier-to-noise density, as the quality of the link is now determined by the uplink.

It is left to the reader to derive the dramatic fall in total carrier-to-noise density if a link from small station to small station is set up. The carrier-to-noise ratio will be 10 dB at a receiver noise bandwidth of only 45 kHz.

It will now be clear that the total carrier-to-noise density of a satellite point-to-point link from a small to a large earth station cannot be improved by the use of an even larger earth station with a better figure of merit, if the uplink carrier-to-noise density is already smaller than the downlink carrier-to-noise density. This situation occurs e.g. in a VSAT network (very small aperture terminals network, chapter 7), where a lot of very small earth stations (1 meter antenna and only a few Watts signal power) are communication with a large so called "hub"-station or with each other via this central hub-station. This type of network is called a star-network.

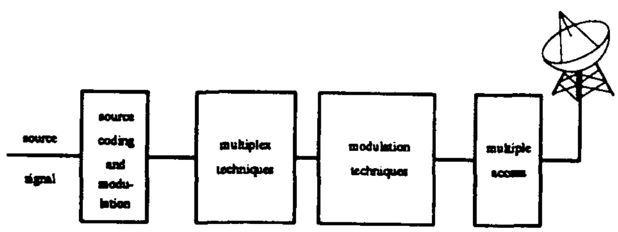
The downlink from satellite to the hubstation of a VSAT network is stronger than the uplink from the VSATs to the satellite, therefore the capacity of the link from VSAT to hub is determined by the e.i.r.p. of the VSATs, which is limited by their size and power. The carrier-to-noise density of the uplink could be enlarged by giving the satellite a larger receiving antenna.

As the uplink from hub to satellite is stronger than the downlink from satellite to VSAT, the capacity of the communication link from hub to VSATs is limited by their figure of merit or, from another viewpoint, the limited e.i.r.p. of the satellite. The larger the e.i.r.p. of the satellite, the larger the capacity of the link to the VSATs is.

Conclusion: Smaller earth stations can be used at the same link capacity, if the satellite is provided with a larger transmitting and receiving antenna. A replacement of the large central station in a star network by an even larger and more powerfull one does not make a difference.

3.5 Signal processing techniques

This section will discuss the signal processing techniques that are used in satellite communications. Fig. 3.11 [5, page 183] shows four levels of signal processing on the source signals (voice, data, and video).



analog	SSB FM	FDM	FM	FDMA
digital	PCM DM	TDM	PSK	TDMA FDMA

Fig. 3.11: Signal processing between user location and satellite earth station

These are modulation or source coding, multiplexing, modulation and multiple access techniques. The processing will bring the carrier frequency of the signal in a frequency range which is typically around 70 MHz (use of coax cable to the earth terminal) or 700 MHz (optical fibre cable to the earth terminal), the "intermediate frequencies". The earth terminal will convert this signal to the higher transmission frequencies in a specific satellite communication band and feed it into a power amplifier (TWT or solid state gallium arsenide) for transmission. The other way round, the earth terminal receives the signal by means of a Low Noise Amplifier (LNA) and downconverts the satellite communications band to the intermediate frequencies.

For the multiplexing (frequency division multiplexing (FDM) or time-division multiplexing (TDM)) a hierarchy was developed, specified in CCIR, CCITT, and U.S. telephone industry standards. In [3] the theory of signal processing and the multiplexing standards are described extensively.

3.5.1 Single carrier transmissions

3.5.1.1 Analog transmission on satellites

Analog transmissions systems can be classified into two distinct types. These are multiple channel per carrier (MCPC) systems, employing carriers modulated by a multiplexed signal representing multiple channels, and single channel per carrier (SCPC) techniques, wherein a single voice channel is assigned its own individual carrier.

- **MCPC:** Analog MCPC systems utilize amplitude modulation (AM) of the individual channel, frequency-division multiplex (FDM) to combine channels, and frequency modulation (FM) on the radio-frequency carrier.
- **SCPC:** Analog SCPC systems employ FM modulation or AM single sideband suppressed carrier (AM SSB-SC) to transmit a single channel on its own carrier frequency.

3.5.1.2 Digital transmission on satellites

Digital transmission systems use both SCPC and MCPC applications as well.

- **SCPC:** In digital SCPC systems the original analog source signal is converted into a digital source signal by employing one of several coding techniques. Coding techniques like pulse-code modulation (PCM) and delta modulation (DM) are used, or adaptive systems such as

nearly instantaneous companding (NIC) or adaptive differential PCM (ADPCM). The modulation of the digital signal on an individual radio frequency carrier is performed by phase-shift keying (PSK).

- **MCPC:** MCPC systems combine multiple digital signals, after analog-to-digital conversion, using time-division multiplexing (TDM). The composited digital signal is then modulated on a wideband radio frequency carrier using PSK.

3.5.2 Multiple access techniques

By using multiple access techniques, more than one pair of earth stations can simultaneously use a satellite transponder. There are three fundamental multiple access system types:

- frequency-division multiple access (FDMA) systems channelize a transponder using multiple carriers, the first multiple access technique that was employed in satellite communications.
- time-division multiple access (TDMA) uses a single carrier frequency per transponder, wherein the full transponder bandwidth is time shared among all users on a time-slot-by-time-slot basis. It is suited only for digital transmission and operates in burst mode.
- code-division multiple access (CDMA) is a method that transforms the signal using a unique code sequence for each user. The different channels use all the same frequency and time. CDMA is only suited for digital transmission.

Most satellite communications systems use FDMA or TDMA. There are many specific implementations of multiple access systems. They are explained in almost every book on satellite communications. The Bibliography contains some recommended literature.

The next two sections will discuss some recent developments in on multiple access systems that are worth mentioning here.

3.5.2.1 Satellite switched TDMA

Modern communication satellites are typically designed with several spot antenna beams providing service to different regions on the earth's surface. Each beam has associated transponder receives and transmitters, and the interconnections between receivers and transmitters are switchable.

In satellite switched TDMA (SS/TDMA) individual uplink beams can be selectively connected to individual downlink beams by an RF switching matrix. This is illustrated in Fig. 3.12 [6]. In such systems it is usually possible for a station in any beam to communicate with stations in all the other beams. The network of RF switches can be commanded from the ground to establish the required channel connections.

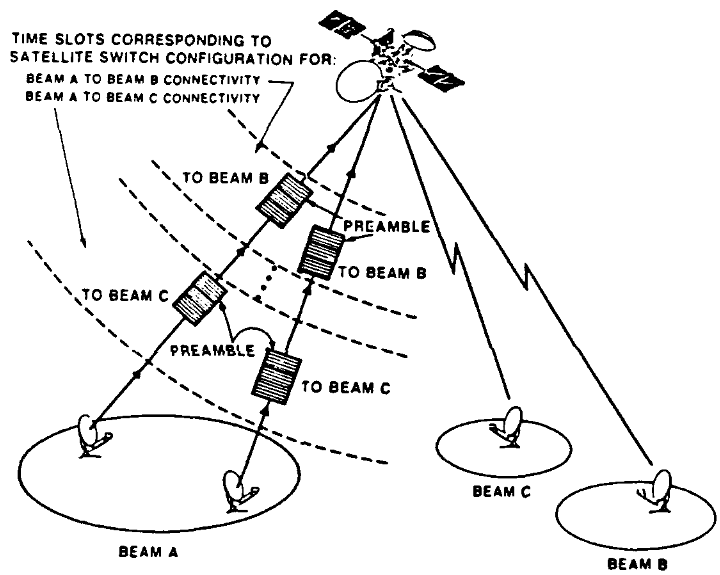


Fig. 3.12: Uplink burst in SS/TDMA system

In normal TDMA, a time slot has been assigned to each earth station. In SS/TDMA however, there is first the division in time-slots correspondent with an individual beam, and second a subdivision into time-slots which correspond with the individual earth stations. An earth station can therefore only communicate with other earth stations within one individual beam. To communicate with earth stations within other beams, reconfiguration of the switching matrix is necessary by command from the ground control earth station.

In a processing satellite, the switching can be done at baseband level. The satellite baseband processing combines by time-multiplexing the incoming bursts into several channels within each

subframe (Fig. 3.13 [6]). The first division in time-slots corresponds to individual earth stations and the second subdivision in time-slots corresponds to individual beams. Different earth stations within the same beam can be addressed and one earth station can address his message to several different beams.

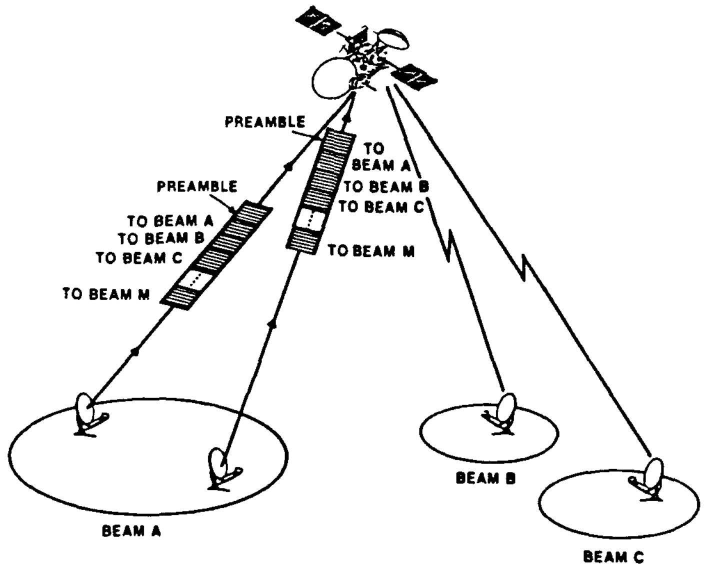


Fig. 3.13: Uplink burst in baseband switched TDMA system

These techniques are very promising to provide flexible satellite communications networking, but the capital investments are large.

3.5.2.2 Code division multiple access

In "direct sequence spread-spectrum", the original message bit stream is mixed with a pseudo-noise code sequence at a higher bit rate. By employing a different code sequence for each communications channel, a Code Division Multiple Access (CDMA) is accomplished. The spread-spectrum technique requires a larger bandwidth than would be necessary for transmission of the original message, but through advanced knowledge of the encoding sequence, the receiver is capable of reconstructing the message under an extremely adverse signal-to-noise ratio.

The technique is called direct sequence spread-spectrum, because a code sequence is "directly" mixed with the original source signal. Another spread-spectrum technique is called frequency hopping [7][8], in which the carrier frequency changes quickly according to a hopping algorithm. Different "codes" for the hopping process are possible, therefore frequency hopping could be used in CDMA as well.

As a result of the noise-like properties of the code sequence in direct sequence spread-spectrum, the interference to other receivers than that to which the transmission is sent appears as a minor rising of the noise floor. On the other hand, interference carriers are spread out in the frequency band by the demodulation process in which the pseudo noise sequence containing the digital message is converted to the small frequency band occupied by the message.

These properties make this multiple access technique very attractive for small mobile satellite communication systems using small omnidirectional antennas which receive unwanted signals coming from other satellites as well [9], [10], [11]. An original motivation for the study of this multiple access technique was, as well as of other forms of spread spectrum transmission (frequency hopping, [7], [8]), to protect military transmission systems from jamming. For this application, the message is spread over a very wide spectrum.

3.5.3 *Comparison of multiple access techniques*

Some properties which are listed below will illustrate the different applications of the several multiple access techniques:

- SCPC/FDMA techniques operate best in networks consisting of a large number of users, each with a relatively small traffic density. They provide the small user with the advantage of multiple access, even though the user may not have the traffic density necessary to support more complex approaches.
- MCPC/FDMA techniques operate very efficiently in heavy point-to-point link applications with few (one or two) wide-band-width carriers occupying the transponder. This provides a large number of channels per transponder.
- TDMA techniques provide a good compromise for those networks with an intermediate number of stations and moderate traffic at each station. They provide excellent interconnectivity and networking capacity for these systems.

- CDMA techniques provide the satellite communications system receivers with a very low sensitivity to interference from other communication signal carriers (own satellite, other neighbour satellites, or terrestrial systems). Frequency hopping CDMA will only cause interference to other systems during the hop period. Direct sequence CDMA transmissions cause a continuous minor interference to the receivers of other communication systems. However, due to mutual interference within the own system (the transmissions on any channel (i.e. code) will rise the noise floor on the other channels) the bandwidth occupancy of the own system will be limited to approximately 10% for direct sequence. The transmissions on any channel (i.e. code) will rise the noise floor on the other channels, because the pseudo random noise sequence will not be despread by the other channels. The self-interference in frequency hopping is larger than that in direct sequence, so that the bandwidth occupancy will be even less [8, chapter 5]. A CDMA system can be used in a frequency band already occupied by another system using FDMA or TDMA, but the bandwidth occupancy of the CDMA system will decrease to less than 10% with an amount that is dependent on the strength of the FDMA or TDMA carriers.

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4 SATELLITE ORBITS AND FREQUENCY BANDS

4.1 Satellite orbits

This section describes the different kinds of possible satellite orbits. There are almost an infinite number of orbits to a satellite, circular or elliptic, but communication considerations limit the usable choices to a relative few.

A very important factor in the choice of an orbit is the orbital period [1]. This orbital period is depending on the distance to the earth. The closer the satellite gets to the earth, the smaller becomes the orbital period. For instance, a satellite at a distance of 1609 km to earth has an orbital period of 1 h 57.7 min. This is not ideal in most cases, because the satellite will not be continuously in line of sight (LOS) of the earth stations.

By using several low orbit satellites, continuous communication is possible by switching the connection from satellite to satellite. This implicates however a more complex system. The lower orbits are therefore mostly used for reconnaissance, navigation, surveillance, remote sensing, meteorology, when a continuous connection to earth is not required.

For communication purposes, the geosynchronous orbit is very attractive. This orbit has an orbital period of 24 h and its altitude is 35.880 km. Since this orbit has the same period as the earth, the satellite will keep the same **longitude** with respect to the ground stations. For continuous communication only one satellite is needed.

Another factor which is very important for satellite communication is the orbital inclination, especially for geosynchronous satellites. Orbital inclination is the angle of the earth axis with the satellite orbital plane axis. The **latitude** of a geosynchronous satellite with respect to the earth surface varies during a 24 h period if the orbital inclination is not zero degrees.

Also the longitude does not remain exactly the same, which can have several causes. Orbital perturbations of artificial satellites can be put into three categories [2, page 46]:

1. Those due to the presence of other large masses (the sun and moon),
2. Those resulting from not being able to consider either the earth or the artificial satellite as a point mass,
3. Those due to nongravitational sources: the radiation pressure of the sun, the earth's magnetic field, micrometeorites and the atmosphere.

The perturbations in gravitational force cause variations in satellite velocity, resulting in a figure eight ground trace of the satellite path on the earth (Fig. 4.1 [1]).

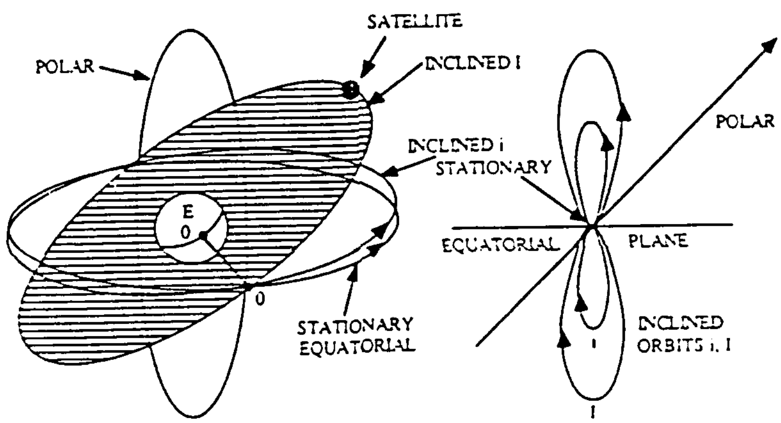

Fig. 4.1: Earth Synchronous Orbits and the Figure Eight of the Subsatellite Point

For communication purposes the geostationary orbit with an orbital inclination of zero degrees is the most practical case, keeping the figure eight as small as possible. This geostationary orbit has, beneath keeping the satellite position with respect to earth the same, another advantage in that the height of this orbit makes a very large area of the earth visible to the satellite. By the use of only three satellites earth coverage is possible except for the polar areas (see Fig. 2.1).

For military applications these areas are not frequently used by Western countries as far as satellite communication is concerned, because they use the geostationary orbit [3]. If satellite communication in the polar regions is desired, the Molniya orbits can be used (see [4] and [5] and

Fig. 4.2, reprinted from [4]). These orbits are named after the Russian Molniya satellites. The Molniya orbits are highly elliptical orbits, with inclination 63.4 degrees.

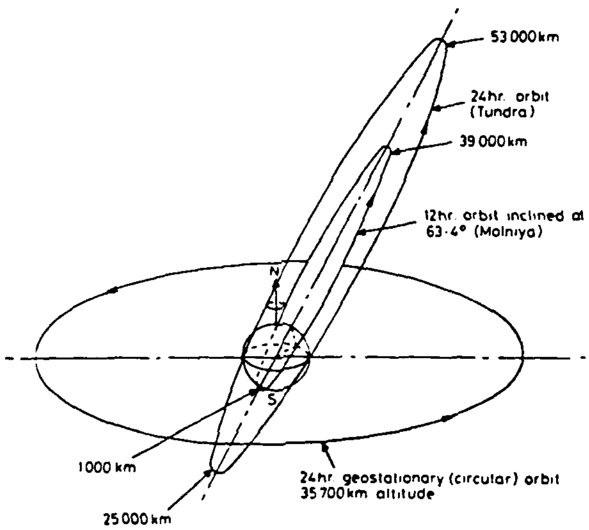

Fig. 4.2: Basic parameters of Tundra and Molniya orbits compared with the geostationary case

At 63.4° inclination to the equator, the two moments which determine the precession of the plane of the orbit cancel. Thus the orbit is quasi-stable and remains fixed in inertial space. If the period of the orbit is fixed to correspond to either an integer multiple or rational fraction of the earth rotational period (sidereal day), then the highest point of the orbit (apogee) always appears over the same point of the earth. The 12 hour Molniya orbit has been used extensively by the USSR for communication satellites for at least 20 years. It is difficult for the USSR to put a satellite in a geostationary orbit, because they do not have a launch platform close to the equator. The typical earth track of a 12 hour orbit is interesting; the satellite stays within a very small region for eight hours (Fig. 4.3, next page). A satellite in this orbit has a shortest distance to the centre of the earth (this is called the Perigee in elliptical orbits) of 1000 km and a longest distance to the centre of the earth (the Apogee) of 39.375 km.

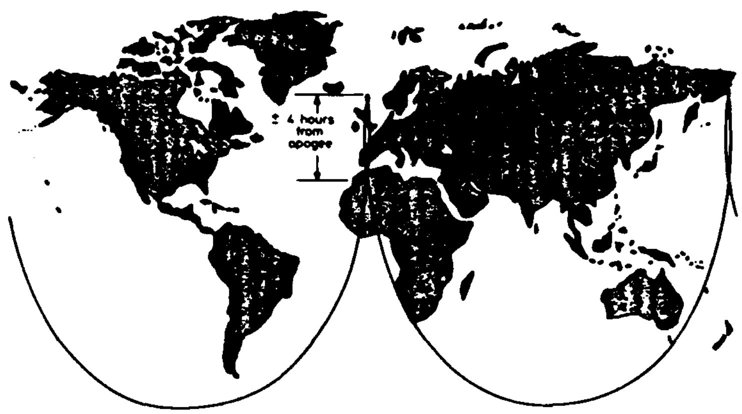

Fig. 4.3: Ground track of a Molniya orbit

The disadvantages of Molniya orbits are: the need for three satellites to cover 24 hours (each satellite provides 8 hours coverage per day); increased orbit decay (and hence shorter satellite life); increased satellite fuel requirements; and greater environmental radiation levels. However, the use of these orbits is presented as a "novel" idea in [6] and [7] to solve the problem of congestion in the geostationary orbit, which is brought by the immense growth of SATCOM use.

4.2 General overview of frequency bands in use

In planning satellite communication systems a lot of interacting factors have to be taken into account to avoid interference to other systems and, more generally, to preserve as far as possible the limited global resources of the geostationary orbit [8, page 62]. Some of these factors are: traffic requirements, other existing (or foreseen) communication systems in the service area, availability of orbital slots, internal interference and mutual interference with other systems, station keeping and antenna pointing accuracy, beam-shaping, advanced antenna technology (e.g. multiple beams with switching matrix), frequency re-use and transmission techniques.

To demonstrate the scale of the problem of orbit-spectrum utilization, it may be noted that in 1988 there were 88 notified space stations using the 6/4 GHz band. With a global arc of 360 degrees this means a satellite spacing of 3 to 5 degrees. There is only some space left for satellites with

large antennas having beamwidths of approximately 1 degree. Probably it is more attractive to use the space that is still left for satellites using the 14/11 GHz or satellites using the 30/20 GHz band which is virtually left empty. However, it should be noted that the optimization of orbit-spectrum efficiency may result in an increase of the system cost.

The frequencies for the different satellite services are allocated by the International Telecommunication Union (ITU). The ITU Radio Regulations include, among other things, the Table of Frequency Allocations, and provisions to limit interference between users of the frequency allocations. Revision of the Radio Regulations is carried out in general and special World Administrative Radio Conferences (WARCs) and in Regional Administrative Radio Conferences (RARCs). The current frequency allocations for the Fixed-Satellite Service (FSS), the Mobile-Satellite Service (MSS), the Broadcasting-Satellite Service (BSS), the Intersatellite Service (ISS) and the Amateur-Satellite Service are listed in [9, APPENDIX C, THE ITU AND INTERNATIONAL FREQUENCY ALLOCATIONS]. As an example, the allocations for the Fixed-Satellite Service are shown in Table 4.1 on the next page [2].

For two main reasons the frequencies used for satellite communication are high. The first reason is the large communication bandwidth that is necessary to make efficient use of such an expensive tool as a communication satellite is. Large bandwidths can only be supported at high frequencies. The second reason is that the satellite antennas have to be small (to keep the satellite weight minimal). Only at high frequencies small antennas can have a high gain. In section 3.1 it is explained already that a high gain is necessary to overcome the attenuation caused by the length of the transmission path of 36000 km between the earth stations and the satellite. Frequencies used for satellite communications are in the ultra high frequency (UHF) band from 300-3000 MHz, the super high frequency (SHF) band from 3-30 GHz, and the lower part of the extremely high frequency (EHF) band from 30-300 GHz (30 GHz for civil use and 44 GHz for military use, see the description of MILSTAR in chapter 5).

Table 4.1: Summary of frequency bands used in the fixed-satellite service

Frequency bands (GHz)			Typical utilization
Current denomination	Up path (bandwidth)	Down path (bandwidth)	
6/4 GHz (C band)	5.925 - 6.425 (500 MHz)	3.7 - 4.2 (500 MHz)	At present the most widely used bands: INTELSAT (IVA, V, VA, VA (IBS), VI). National satellites: Westar, Satcom and Comstar (USA), Anik (Canada), STW and CHINASAT (China), Palapa (Indonesia), Telecom 1 (France), CS-2 (Japan)
	5.725 - 6.275 (550 MHz)	3.4 - 3.9 (500 MHz)	INTERSPUTNIK (Statsionar) USSR (Molyna-3, Statsionar)
	5.850 - 7.075 (1 225 MHz)	3.4 - 4.2 4.5 - 4.8 (1 100 MHz)	Expanded bands allocated by the WARC-79
	6.425 - 7.075 (300 MHz)	4.5 - 4.8 (300 MHz)	300 MHz of bandwidth for Earth-to-space and space-to-Earth links has been set aside for allotment planning by WARC ORB-85, to be completed by WARC ORB-88
8/7 GHz (X band)	7.925 - 8.425 (500 MHz)	7.25 - 7.75 (500 MHz)	Government and military telecommunication satellites
13/11 GHz (Ku band)	12.75 - 13.25 (500 MHz)	10.7 - 11.7 (1 000 MHz)	Expanded bands allocated by the WARC-79
	12.75 - 13.25 (500 MHz)	10.7 - 10.95 & 11.2 - 11.45 (500 MHz)	500 MHz of bandwidth for Earth-to-space and space-to-Earth links has been set aside for allotment planning by WARC ORB-85, to be completed by WARC ORB-88
14/11 GHz (Ku band)	14 - 14.5 (500 MHz)	10.95 - 11.2 11.45 - 11.7 (500 MHz)	INTELSAT-V, VA, VA(IBS), VI, EUTELSAT I, II, (OTS/ECS) USSR (Loutch)
14/12 GHz (Ku band)	14 - 14.5 14 - 14.25 (500 MHz)	11.7 - 12.2 12.5 - 12.75 (750 MHz)	INTELSAT VA (IBS), EUTELSAT I, II (SMS), National satellites: Anik B and C (Canada), SBS, G-Star (USA), Telecom 1 (France), DFS KOPERNIKUS (FRG)
18/12 GHz	17.3 - 18.1 (800 MHz)	BSS Bands	Feeder links for BSS
30/20 GHz (Ka band)	27.5 - 31 (3 500 MHz)	17.7 - 21.2 (3 500 MHz)	Various projects under study (Europe, USA, Japan), NATIONAL SAT CS-2 (Japan), ITALSAT (Italy).

Equal bandwidths for the uplink and downlink transmissions are desirable to allow full utilization of an allocated band. Historically, the 6 and 4 GHz bands ("C bands") have been commonly paired and most existing fixed satellites systems use these frequencies. Governmental (i.e. Military) transmissions use the 8 and 7 GHz bands ("X bands") for mobile as well as fixed satellite communications. A number of fixed satellite systems (e.g. for television broadcast) are also operating at 14 and 11 GHz or 12 GHz ("Ku bands") and a few in the 30 and 20 GHz bands ("Ka bands"). Mobile systems operate in the 225-400 MHz band (Ultra High Frequency (UHF)), in the 1.6 and 1.5 GHz bands (L-band) and in the 2.35 GHz band (S-band). All these systems are capable of using a common antenna system for transmitting and receiving since the ratio of up-path to down-path frequencies is less than 1.5. Another advantage for this arrangement is that propagation conditions are relatively similar on both up and down links and that polarization effects (see section 3.1.2) are likely to be correlated. Also, if the channel plan (division of the overall frequency band into smaller frequency bands or channels) for both links is made identical, the satellite transponder translation frequency can be kept constant for every channel.

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5 SYSTEM ELEMENTS IN SATELLITE COMMUNICATION

The satellite communications system can roughly be divided into two parts; the space segment (the "satellite") and the ground segment (called "earth station" or "terminal")

5.1 The Satellite and its communications payload

5.1.1 Satellite subsystems

A communications satellite consists of several subsystems, of which the communications part (the satellite communications payload) is formed by the communications transponders and the antennas. The communications transponders receive, amplify, process, and retransmit signals, while the antennas capture and radiate signals. The other subsystems are:

- **The structure**, which supports the spacecraft under the launch and the orbital environment.
- **The attitude control**, which keeps the antennas pointed at the correct earth locations and the solar cells pointed at the sun.
- **The primary power**, which supplies the electrical power to the spacecraft. This power is derived from the solar cells and from rechargeble batteries during the period in which the satellite is in the shadow area of the earth.
- **The thermal control**, which maintains suitable temperature ranges for all the subsystems during the periods in which the satellite is in the shadow area of the earth, and during the periods in which the sun burns on the satellite.
- **The propulsion**, to maintain the orbital position, and to perform major attitude control corrections, orbital changes, and initial orbit deployment.
- **The telemetry, tracking, and command (TT&C)**, to monitor the spacecraft status, the orbital parameters, and to control the spacecraft operation (think of SS/TDMA).

The satellite communications payload is the communications package of the satellite. The functions of the payload are to receive uplink carriers, process them, and retransmit the information on the downlink. The downlink commonly uses the lower frequency, which suffers lower attenuation and thus eases the requirement on satellite output power. The communications payload of the satellite may be considered as a distant repeater which functions in much the same way as a line-of-sight microwave radio relay link repeater does in a terrestrial transmission.

5.1.2 The satellite transponder

A satellite transponder is the key element of a communications satellite. It is the path of each channel from receiving antenna to transmit antenna. A satellite **repeater** consists of the transponders, or channels, between one transmitting antenna and one receiving antenna including these antennas (Fig. 5.1). Usually a diplexer is used which enables the transmitting and receiving antenna to be the same antenna. Each transponder isolates neighbouring RF channels, translates the uplink frequency to the downlink frequency to minimize interference between transmitted and received signals, and amplifies the signal.

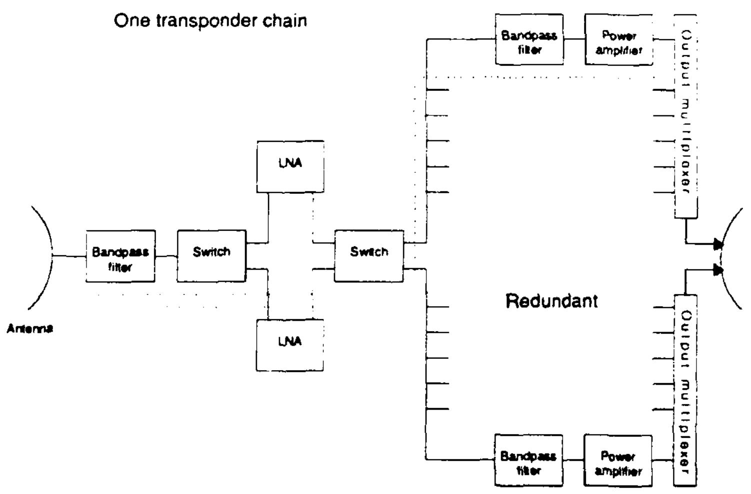

Fig. 5.1: A satellite repeater

Quasi-linear transponders are the transponders using a travelling wave tube amplifier which is operated at a backoff of 4 to 6 dB. **Linear** operation with TWTA transponders can be achieved through the use of linearizers [1, page 285]. Another approach is to use a solid-state FET-amplifier, which has a more linear transfer characteristic when near saturation than a TWTA. **Hard-limiting** transponders are transponders equipped with a limiting device which clips the incoming signal. It permits the travelling wave tube amplifier to be operated at saturation with output power virtually independent of the input power. **Regenerative** transponders use on-board signal processing of digital signals to perform switching, regeneration or baseband processing.

These techniques have not been widely used up to now but will find applications in future satellites.

5.1.3 Transponder amplifiers, filters and oscillators

For High Power Amplifiers (HPAs) travelling wave tubes (TWTs) have been used as the output amplifier for many years. They are the most significant contributors to nonlinear impairments. The lifetime of the transponder package itself is generally considered to be dependent on the lifetime of the TWTA. Considerable efforts have been devoted to extending the life expectancy of the TWT for satellite applications. Continuous improvements in life and performance of solid-state gallium arsenide field-effect transistor amplifiers have made the use of solid-state devices more and more attractive. They tend to remain more linear and then to saturate abruptly. Although they are not as efficient as TWTs, they will have longer life.

Low noise amplifiers are at the front end of a communications satellite transponder. They must provide a low noise figure and high gain. Early designs employed bipolar transistors and tunnel diode amplifiers whereas modern designs employ field-effect transistors using gallium arsenide technology (GaAsFET).

The intermodulation caused by the amplifiers and the interference from other channels must be reduced by filter techniques. The group delay produced by these filters causes intersymbol interference on digitally transmitted information or phase distortion on an analog carrier. The filters used in satellite transponder designs therefore are equipped with equalizing circuits that minimize the group-delay distortion effects.

Oscillators, used to convert the uplink to the downlink frequency, are also a critical source of spurious outputs from satellite transponders. This comes from frequency instability, local oscillator harmonics and phase jitter.

5.1.4 Satellite antennas

The satellite and earth station antennas are performing the same operations, which are the following [2]:

- The simultaneous reception and transmission of communication signals
- The rejection of interference from neighbouring systems, both space and terrestrial
- The maintaining of accurate pointing between earth station and satellite

More about the antenna system will be described in the next section about earth stations, as the satellite and earth station antennas are essentially the same. The differences between satellite and earth station antennas are in the size and weight of the antenna. Satellite antennas have to be as light as possible. They cannot be too large, because of the weight and the requirement of complex pointing equipment on board the satellite. The design of electronically steered phased array antennas is therefore very important for future satellites with steerable spot beams (section 3.2.3.1).

5.2 Earth stations

The equipment on the surface of the earth is called an earth station, regardless of whether it is a fixed, ground mobile, maritime, or aeronautical terminal. An earth station consists of the subsystems in the following list. The first four systems listed below will be discussed in the next sections. Fig. 5.2 shows a typical earth station system block diagram [3].

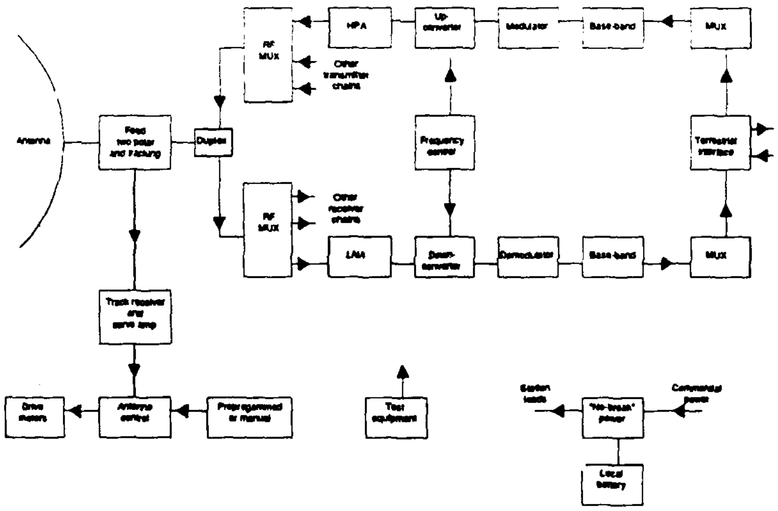

Fig. 5.2: Earth station block diagram

- Antenna system
- Tracking system
- Receiving system
- Transmitting system
- Terrestrial interface: to change the communication signals from the formats, in which they are brought to the station by microwave and cable systems using either frequency- or time-division terrestrial multiplex methods, into formats suitable for satellite transmission
- Primary power: varying from plain battery- or solar-cell-operated remote transmitters to huge combined commercial power and diesel generator systems
- Test equipment: for routine measurements of voltage, power, temperature and specialized measurements unique to satellite communication (e.g. the noise power ratio (NPR) to measure the intermodulation noise for FDM systems and the G/T of the earth station)

5.2.1 The antenna system

The antenna system is composed of the antenna proper, typically a reflector and feed (Fig. 5.3 [4]), separate feed systems in the case of monopulse tracking (see next section), and a duplex and multiplex arrangement for simultaneous connection of several transmit and receive chains to the same antenna. The use of a subreflector in the antenna system gives the opportunity to place the feed beneath or at the center of the main reflector, thus providing easy access to the feed and more flexibility in the overall design of the antenna configuration (e.g. Cassegrain antenna, Gregorian antenna, offset antenna [1, page 240]).

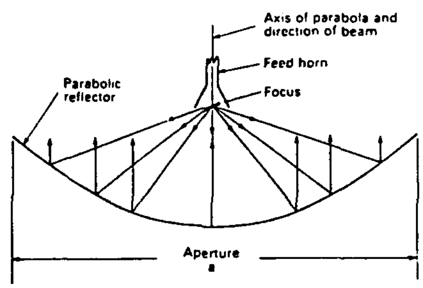

Fig. 5.3: Geometry of horn feed and parabolic reflector

The antenna characteristics are the most important of all in determining the overall earth station performance, both on the uplink and downlink, because the physical size of the earth station antenna directly determines the carrier-to-noise ratios achievable on these links, given fixed transmitter powers and geographical coverages. The most important antenna characteristics in the system planning have been discussed in section 3.1

The reflector type antenna is the most widely used in satellite communications, but some other types are use as well. Other types are horns (used as primary feeds for reflectors and also as global coverage antennas on satellites), lenses (dielectric or waveguide types), and phased arrays. For satellite communications at the UHF-band helical antennas are used, Fig. 5.4 [5]. They consist of a spiral connected to a straight bar for robustness.

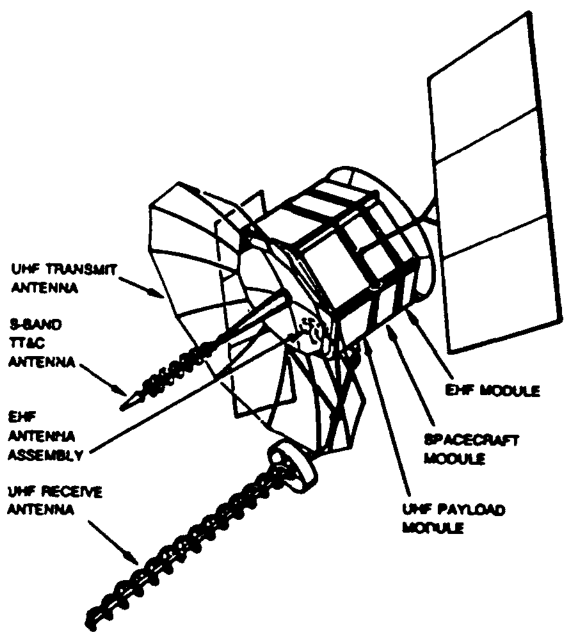

Fig. 5.4: Helical antenna (UHF receive antenna) on the FLTSATCOM Satellite

5.2.2 The tracking system

The tracking system comprises whatever control circuit and drives are necessary to keep the antenna pointed at the satellite. The pointing has frequently to be changed, e.g. to switch from one satellite to another, but also to follow the residual orbital motions of a geostationary satellite and to allow for wind deflection of the antenna. The necessity for tracking increases as the beamwidth of the antenna gets narrower (i.e. the antenna surface gets larger).

A hierarchy of pointing and tracking can be identified. For small antennas only **fixed pointing** is necessary. By **occasional repointing** several satellites can be used. The adjustments can be changed manually. Larger antennas require at least a **preprogrammed tracking** to follow "open loop" the figure eight (section 4.1) of the satellite. A more sophisticated method is **step tracking** which used a servomechanism in which the antenna is moved a discrete amount in one step, and if the signal level increases, it is moved again in this direction. As soon as the signal level does not increase, it returns to the previous position. **Fully automatic tracking** is achieved by the monopulse or simultaneous lobing system. Four beams are generated in an auxiliary feed, and combinations of the signals from these four beams provide left-right and up-down error signals. These error signals are used to generate control signals for driving the antenna by precise two-axis drives (azimuth and elevation). Such systems are required only for narrow beamwidths, typically less than one-fourth of a degree.

5.2.3 The receiving system

The signals to be received from the satellite are extremely weak and must therefore sufficiently be amplified without the addition of much thermal noise to enable the following receiving stages to perform their functions with an adequate carrier-to-noise ratio. Therefore low noise amplifiers are used. To get the most benefit from the LNA, it must be located as near as possible to the antenna feed.

The receiver chain further consists of the down-converters and demodulators. Downconversion can be accomplished in one step directly from the satellite downlink carrier frequency to the intermediate demodulator frequency (e.g. 70 MHz). To reject image frequencies however down conversion is performed in two steps in most cases. If the received signal is broadband, the microwave receiver system splits the signal into several narrow band chains before the downconversion starts.

5.2.4 The transmitting system

Before transmission to the satellite, the baseband signal is modulated on an intermediate frequency and upconverted to the satellite uplink carrier frequency. The signal is then fed into a high power amplifier, which can be a travelling wave tube amplifier (TWTA) [6], [7], one or more Klystron amplifiers or a solid state amplifier.

The advantage of TWTAs is their wide bandwidth. Disadvantages are their intermodulation products (a common problem when applying a wideband amplifier handling several carriers) and their high price. If Klystron amplifiers are used the system is less flexible because they have a narrow bandwidth, so retuning is necessary to change frequencies. In addition there is the complicated problem of multiplexing many chains on an antenna without interaction among the amplifiers. Klystron amplifiers however are cheaper and simpler and because there are fewer single-point modes of failure, the reliability is higher. For small earth stations, the solid state amplifiers are commonly used.

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6 OVERVIEW OF CIVIL SATELLITE COMMUNICATION SYSTEMS

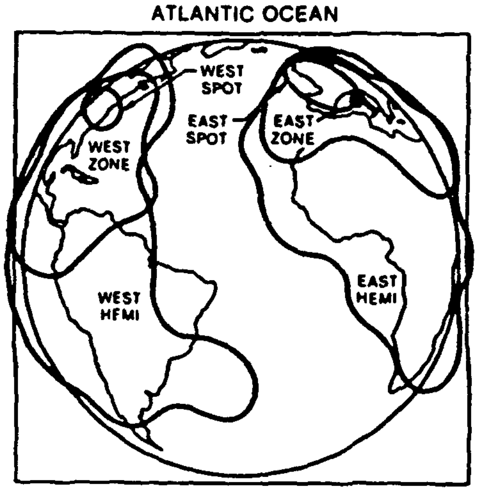
This chapter gives an overview of the existing civil satellite communication systems. The overview contains a global description and the applications of the systems. The first part contains information about international systems, the second part features regional or sub-regional systems and the third part contains dedicated national FSS systems for domestic services. Extensive data on each network is not provided here, but can be found in tables of references [1], annex III and [2]. The data includes satellite platform and communication sub-system design features, earth station characteristics, and satellite orbital positions (especially in [2]). A short world view of satellite systems is given in [3].

6.1 International systems

6.1.1 Intelsat system

The International Telecommunication Satellite Organization (INTELSAT) is an organisation with 114 member nations. The system is used primarily for international commercial communications and by many countries for domestic commercial communications. INTELSAT links together more than 165 countries, territories and dependencies around the globe. Currently, the operational system consists of two Intelsat IVA satellites, four Intersat V, four Intelsat VM (the same as V but with a maritime communications subsystem which is leased to Inmarsat) and three Intelsat VA. The Intelsat V coverage is shown in fig. 6.1 [1]. This satellite is still the backbone of the current system. The communication subsystem of Intelsat V is shown in Fig. 6.2 [1].

ATLANTIC OCEAN



INDIAN OCEAN

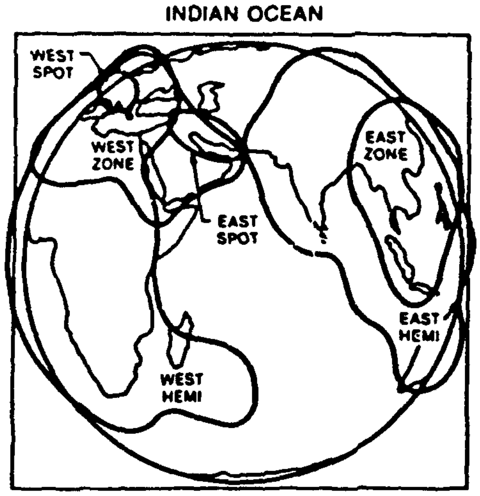
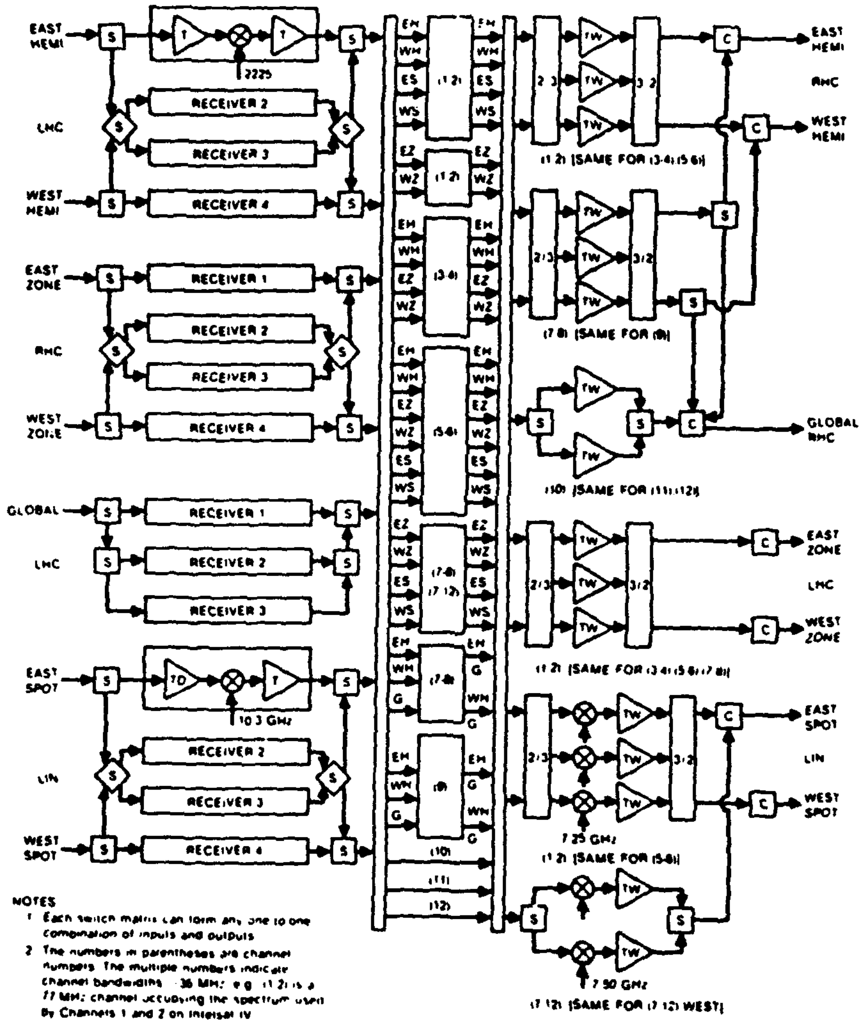


Fig. 6.1: Intelsat V Antenna Patterns



NOTES
1. Each switch matrix can form any one to one combination of inputs and outputs
2. The numbers in parentheses are channel numbers. The multiple numbers indicate channel bandwidths > 36 MHz; e.g. (1-2) is a 77 MHz channel occupying the spectrum used by Channels 1 and 2 on Intelsat IV
3. LHC/RHC = Left/right hand circular polarization
   LIN = Linear polarization
4. Channels (7-8) and (9) may each be used on both EH and WH or on global
5. Spot beam antennas have diplexers (not shown)
6. Combiners after transmitters also have inputs from unillustrated transmitters

Fig. 6.2: Intelsat V Communication Subsystem

This detailed picture demonstrates the complexity of the satellites of today. The next generation of satellites, INTELSAT VI, will have a capacity of up to 24000 voice circuits and capable of transmitting at least three television channels. Five satellites will be launched to 1992.

The INTELSAT ground stations are owned and operated by telecommunications organizations in the countries in which they are located. INTELSAT has set the earth station standards related to space segment access. Each Signatory is responsible for compliance with these standards.

INTELSAT provides the following general categories of services:

1. International Telephony Service, which includes international telephone, data, telex and facsimile services. Various modulation/access techniques are employed (FDM-FM, SCPC, TDMA). Digital services are provided for voice and data, allowing the use of digital circuit multiplication equipment (DCME) to derive additional channels from the same satellite capacity.
2. International Television Services, which comprises virtually all intercontinental television service. The earth station network includes transportable "fly-away" and smaller receive-only antennas.
3. INTELSAT Business Service (IBS), tailored to meet the specific needs of the business community. It offers the possibility to utilize smaller earth stations on, or close to, user premises to minimize total communications costs.
4. INTELNET, a digital service designed for data collection and distribution using small, inexpensive microterminals and a large central hub earth station.
5. VISTA Service, for domestic and international telecommunications services to rural and remote communities.
6. Domestic telecommunication services, which offers the purchase or long-term lease of INTELSAT transponders to satisfy domestic communications requirements.

The frequency bands used are the 6/4 GHz band (C-band) and the 14/12 GHz band (Ku-band).

In the new environment of competition and coexistence with fibre optics, Intelsat dismisses the now increasingly rare claim that the arrival of fibre optic cables marks the end of satellite usage on thick routes [4]. Intelsat will continue to enhance, strengthen and extend the interconnectivity of its system and develop and upgrade its service offerings to changing customer needs. Intelsat

will make use from the SATCOM flexibility in providing new communication needs, not requiring any existing communication infrastructure. An immense market is expected in developing countries of the Third World. From the range of services offered by Intelsat it is clear that it can fulfil almost every requirement that one might need.

6.1.2 Inmarsat system

The International Maritime Satellite Organization (INMARSAT) was created in 1979 and has been operational since 1982 [5]. The organization's original purpose was to provide satellite facilities in order to improve maritime communications. In 1985, the Inmarsat Convention was amended to give Inmarsat a mandate to provide aeronautic communications. Inmarsat signed a contract with British Aerospace for the purchase of three new maritime communications satellites. The organization is required to operate on a normal commercial basis.

Inmarsat's Council consists of representatives of the 18 signatories with the largest investment shares and four others elected on the principle of a just geographical representation. The Council has the responsibility of making provision for the space segment and oversees the activities of the Directorate (the permanent staff of Inmarsat). For its first generation system, INMARSAT leases the Marecs-A and Marecs-B2 satellites from the European Space Agency, the Maritime Communications sub-systems (MCS) on three Intelsat V satellites from the Intelsat organization and capacity on three Marisat satellites from COMSAT General. The new Inmarsat-2 satellites are expected to go into service in 1990. Unlike the first generation systems, they will be owned and controlled by Inmarsat.

Inmarsat provides the following services to the shipping and offshore industries:

1. Telephone, telex, data and facsimile
2. Distress and safety communications

At the beginning of 1988 there were already over 6000 ships equipped with ship earth stations (SES). The services are available in all three ocean regions (Fig. 2.1).

The network is comprised of a fixed-satellite service (FSS) component (the coast earth stations) and a mobile satellite service (MSS) component. Fig. 6.3 shows the configuration [6].

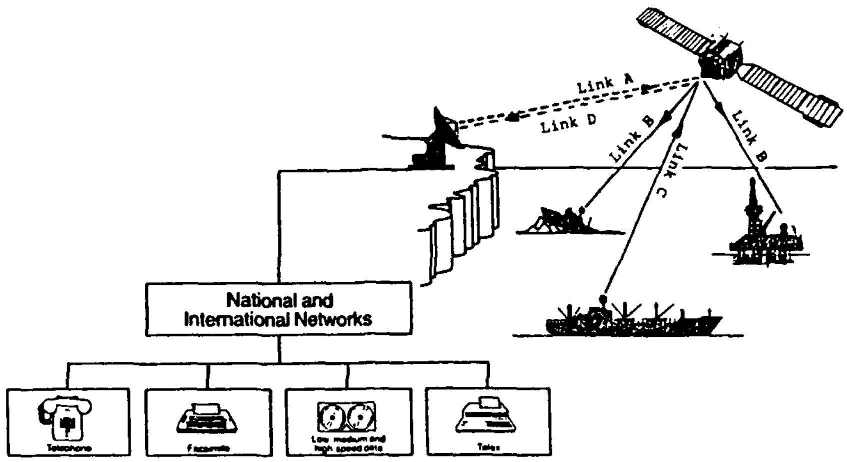


Fig. 6.3: A general view of the Inmarsat system

Link A is the 6.4 GHz band, link B the 1.5 GHz band, link C the 1.6 GHz band and link D the 4.2 GHz band (first generation INMARSAT). Per link Inmarsat uses a total bandwidth of approximately 8 MHz. The second generation Inmarsat system will have a capacity increase of factor three. Link D changes to the 3.6 GHz band.

Maritime services will continue to be central to Inmarsat's future operations, but a number of new services and ship terminals are planned to enable much wider use to be made of Inmarsat by all types of mobile stations [7]. In 1988 there were 20 coast earth stations (CES) in operation, while a further 18 CES were planned.

There are now a number of standard mobile earth stations that may be used namely: the Standard A, Standard C, Aeronautic stations [6] and EPIRBs (emergency position indicating radio beacons). The standard A stations are able to provide the two groups of services mentioned before. The standard C earth station is intended as a much cheaper data-only terminal providing message transfer with terrestrial telex and data networks, with a transmit and receive capability. Transmit is at 300 bits per second for 1st generation satellite and at 600 bits per second for 2nd generation. Reception will be at an information data rate of 600 bits per second. With this new terminal the market is opened for aeronautic and land mobile applications [8].

6.1.3 Intersputnik

Intersputnik - the International System and Organization of Space Communications - is an open international organization. It represents sixteen members, all with communist governments. The headquarters of INTERSPUTNIK is in Moscow, USSR. INTERSPUTNIK leases two Stationar satellites belonging to the USSR. They are located at 14 degrees West (Atlantic region) and 80 degrees East (Indian region). Quality standards of telephone and television channels are in keeping with CCIR and CCITT Recommendations. The satellites use the 3.8/3.7 GHz band.

6.2 Regional and sub-regional satellite systems

In this category there are two satellite systems namely the Eutelsat system and the Arabsat system. For the sake of consizeness, only the Eutelsat system will be discussed. The interested reader is referred to [2, ANNEX III] for information about the Arabsat system.

6.2.1 Eutelsat

The European Telecommunication Satellite Organization (Eutelsat) is an international organization created in 1985 which has 26 member countries. It replaced Interim Eutelsat, created in 1977 by the PTT administrations of 17 European countries.

The four satellites, called Eutelsat I, use the 14.00-14.50 GHz band on the uplink and the 10.95-11.20 GHz, 11.45-11.70 GHz and 12.500-12.583 GHz bands on the downlink. EUTELSAT plans to introduce its second generation of satellites (Eutelsat II) from 1990. They will offer more capacity - the 12.500-12.583 GHz downlink band of Eutelsat I will be extended to a 12.50-12.75 GHz downlink band - and a high gain beam covering central Europe for TV distribution to small dish receivers.

The telecommunication services are:

1. Telephony and low speed data, provided by 8 bit PCM encoded voice and data signals in TDMA at 120 Mbit/s. There are 15 stations in operation and 3 others are being constructed;
2. Television, consisting of EUROVISION transmissions. The modulation method is FM. The earth stations are the same as the ones used for telephony and low speed data (standard TDMA/TV earth stations);

3. Business services, a Satellite Multi-Service System (SMS), provides satellite channels suitable for various integrated digital communication services for business applications. There are two networks, one with SCPC/SMS channel access and one with TDMA/SMS channel access. For the last one the French domestic satellite Telecom 1 is leased;
4. Transponder leasing, of which the largest demand is for satellite TV distribution applications, by the PTT administrations;
5. Other services, such as direct TV broadcasting (DBS) or land mobile.

6.3 Dedicated national domestic systems

Domestic satellites are owned by the following countries: Australia, Brazil, Canada, China, France, the Federal Republic of Germany, India, Indonesia, Italy, Japan, Luxembourg, Mexico, Sweden, the United States of America and the USSR. An overview of the satellite systems of these fifteen nationalities is given in the CCIR Handbook on Satellite Communication, fixed satellite service [2]. For details about the satellites, the reader is referred to [1]. As the launch rate of satellites is very high, these references will remain up to date only a short while. However in magazines like "Funkschau" or "Cable and Satellite" details of new communication satellites are published regularly. Two examples of dedicated national domestic systems are given in the next two sections.

There can be given ma. more interesting examples like the France Telecom 1 [9] and 2 system, used for both civil and military satellite communications, and the Japanese plannes with Superbird, a dual-band satellite having 19 (14/12 GHz) transponders and 10! (30/20 GHz) transponders. From this it will be clear that satellite communication is in fact still at an early stage of its development.

6.3.1 Canada

In chapter 2, two link budgets were illustrated in tables 2.2 and 2.3. They concerned the Canadian Anik D satellite, operated by Telesat Canada. Because Canada was the first country in the world to operate a geostationary domestic satellite system, the Canadian satellite system can be seen as a very illustrative example. The communication service requirements in Canada are dictated largely by the country's geography. Communication satellites are an effective and reliable method for providing services to many small communities outside of the heavily populated urban centres.

The first Canadian satellite Anik A-1 was geostationary and operated in the 6/4 GHz band. It was soon followed by two similar satellites Anik A-2 and A-3. Canada's second type of satellite was Anik B (the one of table 2.2 and 2.3) which was the first commercial dual-band (6/4 GHz, 14/12 GHz).

The current Telesat Canada operating system makes use of two 6/4 GHz satellites (Anik D) and three 14/12 GHz satellites (Anik C). Anik D utilizes a single shaped beam for both the transmit and receive bands. A frequency re-use plan (utilizing vertical and horizontal linear polarization) increases the channel capacity by a factor two. The same idea is applied to Anik C. However, the uplink is a single Canada wide shaped beam while the downlink coverage is divided onto four regions with each beam covering a quarter of Canada, which allows very small receiving stations in broadcasting applications.

The services provided are television services (high quality network trunking for the exchange of programming between regional centres for later rebroadcast and medium/low quality broadcasting of educational material or entertainment programmes), radio programme service, telephone message services (medium/heavy route trunking between major centres and a light route service for small remote communities or industrial locations) and data services (for corporate data communications networks, government services for remote control/data acquisition at unmanned sites and for data broadcasting). Table 6.1 on the next page shows the details of the Canadian satellite network. The next generation of Telesat satellites will be dual-band (Anik E). It will combine the capabilities of Anik C and Anik D.

Table 6.1: Canadian network descriptions

Administration/Organization: Telesat Canada

Satellite platform

No.	Satellite identification	Manufacturer	No. of satellites in system	Date of 1st launch (year)	Type of stabilization	Design life (years)	Mass in orbit (kg)	Power at end-of-life (W)
1	Anik C	Hughes	3	1981	spin	10	567	800
2	Anik D	SPAR Aero-space	2	1982	spin	10	635	800

Satellite communication sub-system

No.	Freq. band polarization (GHz)	Coverage areas	e.i.r.p. (e.o.c.) (dBW)	G/T (e.o.c.) ($dB(K^{-1})$)	Receive antenna gain (e.o.c.) (dB)	No. of transponders	Transmit power/ type (W)	Transponder bandwidth (MHz)	Sat. power flux-density ($dB(W/m^2)$)
1	14/12 linear	Canada North USA	47	+3	34	16	15/TWTA	54	-81
2	6/4 linear	Canada North USA	38	0	30	24	11/TWTA	36	-81

Earth station characteristics

No.	Station type	Freq. band polarization (GHz)	Antenna diameter (m)	e.i.r.p. (dBW)	G/T ($dB(K^{-1})$)	Receive antenna gain (dB)	Modulation type	Access method
1	Telephony Tx/Rx	14/12	8	80	35	58.0	PCM 91 Mbit/s	SCPT
2	TV Tx	14	4.5-8	74-76	-	-	TV-FM	FDMA
3	TV Rx	12	4.5	-	26.5	53.0	TV-FM	FDMA
4	TVRO	12	1.2, 1.8	-	15.0,18.0	41.5, 45.0	TV-FM	FDMA
5	Heavy traffic	6/4	30	82	38	60.0	FM-FDM	FDMA
6	TV	6/4	8-10	81.7	28-30	48.5-50.5	TV-FM	SCPT
7	Light traffic	6/4	4.5	44.7	21	43.5	SCPC-PSK	FDMA

6.3.2 Luxembourg

The Satellite Control Facility (SCF) of the Astra satellite network is situated in Luxembourg. Astra is one of the well-known "direct-broadcasting" satellites (other are e.g. France's TDF1, Germany's TV SAT 2), that are used solely for the delivery of television in Europe. It is the first satellite launched by the Société Européenne de Satellites (SES).

The SCF consists of two parts: the Satellite Operations Centre (SOC) with an 11 metre antenna for tracking, telemetry and command (TT&C) and a Network Operations Centre (NOC) with a Communications Earth Station (CES). The CES transmits and monitors the television channels to and from Astra in the 14/11 GHz band. Also user facilities outside Luxembourg may broadcast television programs via the Astra satellite.

The satellite itself has an in-orbit mass of 1045 kg. It is positioned in a geostationary orbit at longitude 19.2°. The transponders have a 26 MHz bandwidth which is the typical bandwidth of an FM modulated television channel that is to be transmitted by satellite. The high power amplifier for each transponder has an output power of 45 Watts and is, as usual, a TWTA. Redundancy is provided by 4 receivers for 2 actually used receivers and 22 transponders for 16 transponders. The two receivers are needed to receive the two (orthogonal linear) polarizations of the transmitted signals on the uplink. The 16 transponders can support the same number of television channels. The e.i.r.p. of each television channel on Astra is 50 dBW. The television channels can be received by a Television Receive Only (TVRO) station equipped with a dish of only 60 centimetre in diameter.

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7 FUTURE DEVELOPMENTS IN CIVIL SATELLITE COMMUNICATIONS

Satellite communication organisations are going to exploit more and more the unique possibilities of satellite communication, because of the success of optical fibre communications. Satellite communication offers flexibility (think of setting up an emergency network), mobility, communication to low density population areas, the easy provision of private networks, and heavy trunk connections. Despite the improvements in optical fibre communications, international satellite communications are more reliable and can offer still enough capacity [1].

7.1 Land (and aeronautic) mobile communications

Land and aeronautic mobile satellite systems are only an emerging technology at this stage. The history of satellite communications with mobiles is principally that of maritime communications (COMSAT, MARISAT, MARECS etc.) [2]. Although Inmarsat has been operational for several years providing satellite communications to more than 8000 large and medium-sized ships, interest in satellite-based systems from the land and aeronautic mobile sectors is only recent.

The aeronautic community, like the maritime community, operates on a global basis and has a need for reliable, worldwide communications links, standardized technology, and systems for safety, airline operations, and passenger communications.

The aeronautic and land mobile market still has no dedicated operational satellite providing a service. When compared to the classical cellular system, satellite systems cannot compete in respect of system capacity, cost, spectrum efficiency, etc.. However a satellite system should be considered for what it can best provide, i.e. **wide area coverage** and **flexibility** [4].

Wide area coverage allows the extension of the system coverage to coastal waters and to regions which are economically important to Europe, e.g. the Middle-East and North-Africa. It also offers the possibility to complement radio cellular systems in low density areas.

Flexibility can be translated in terms of fast implementation of new services, but also of ability to adapt to new situations, as for instance after natural disasters, when the terrestrial infrastructure has been damaged.

The benefits of satellite coverage for mobile systems have a real attraction for large land masses with low population densities. Canada, the USA and Australia are prime examples of nations with low population densities that have been in the forefront of land mobile satellite development. The MSAT studies in North America and the earlier NASA ATS-6 satellite launched in 1974 have investigated and demonstrated the potential of land mobile satellites. In Europe, the land mobile initiative has been coordinated largely through ESA. An extensive set of trials demonstrated various aspects of land mobile systems using the Marecs satellites through the Prosat and Prodat projects. A mobile network concept is shown in Fig. 7.1. Several relatively large fixed earth stations communicate with several small mobile earth stations and with each other.

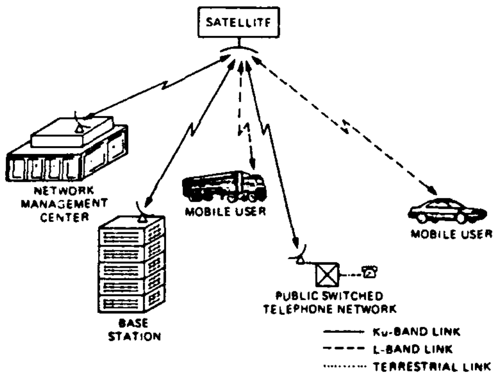

Fig. 7.1: Mobile-satellite-network concept [3]

Amongst the services which are foreseen, priority is given to those which are not offered by cellular systems, and in particular low-rate (including paging) and medium-rate data transmission services, and private networks.

Quiet recently the first operational private data satellite service for mobile communications has been developed. The system is developed in the United States [7]. The system terminals operate in the Ku-band (12/14 GHz), which is remarkable because of the risk of fading at these frequencies. The use of Ku-band does require a directional antenna and sophisticated signal processing. Once developed, however, these turn into assets which enhance throughput and reduce interference and multipath [8]. It is clear that exploitation of a European satellite system

for mobile communications must be decided in the near future, otherwise non-European companies will jump in to fill the demand [9].

7.1.1 PRODAT

An example of a low data rate mobile system is the PRODAT system developed by ESA. Communications through space are provided by MARECS, a maritime communications satellite. The following services can be provided by PRODAT:

a) sending of messages from fixed to mobile users and vice-versa, and from mobile to mobile users (via a "hub" earth station)
b) sending of messages to multiple mobile users (broadcast)
c) request/reply functions
d) periodic polling of mobiles
e) paging

Prodat offers mobile communications between a central relatively large "hub" earth station to maritime, aeronautic and land mobile users with very small earth stations. The mobile earth stations are equipped with omnidirectional antennas that have the size and form of a turned flower-pot. The access scheme is Code Division Multiple Access (CDMA, section 3.4.3.2) to avoid interference with other systems, because of the omnidirectional antenna. The data rate is only 200 bits/s for transmission and 50 bits/sec for reception.

In chapter 3 it is explained in the discussion on link budget calculations that these data rates cannot be enlarged by employing a larger central earth station. By using the PRODAT mobile earth stations the data rate can only be larger if the uplink carrier-to-noise ratio is improved. The only parameters that can be improved when the earth stations are kept the same size are the efficiency of the power amplifier of the mobile earth station, or the figure of merit of the satellite (providing the satellite not with an earth coverage antenna, but for example with several spot beam antennas).

The link budget for the uplink from mobile station to satellite is as calculated below. It is assumed that a bandwidth "b" of 200 Hz is required for the 200 bits/sec data signal.

Table 7.1: Link Budget for the uplink to the Marecs satellite at 1.6 GHz

Amplifier output power	P_e	10.0	dBW
Omnidirectional antenna gain	$+G_{et}$	+0.0	dB
Earth station radiated power	$(e.i.r.p.)_e$	10.0	dBW
Free-space path loss	$-L_{p,u}$	-187.7	dB
Satellite figure of merit	$+(G/T)_s$	-12.0	dB/K
Boltzmann's constant	-k	-228.6	dBW/K·Hz
Rain loss, dry weather	$-L_{r,u}$	-0.0	dB
Carrier-to-noise density	C/N_o	38.9	dB·Hz
10 log bandwidth	b	-23.0	dB·Hz
Available Carrier-to-noise density	C/N	15.9	dB

7.1.2 Inmarsat

The Inmarsat system is also expected to be used for land mobile communications and all forms of aeronautic communications (including air traffic control, airline operations, and passenger communications). The satellite system will support both telephony and data communications [5]. The standard C stations from Inmarsat can provide a communication services similar to Prodat, but there is a difference. The central Inmarsat station (CES) of the system is connected to the terrestrial network. The Prodat system however uses a direct link to a private central station owned by the company employing the system [6]. The standard-C can use antennas as small as 20 cm high and electronics which can be accommodated in an enclosure slightly bigger than a car radio.

7.2 Very small aperture terminals (VSATs)

7.2.1 VSAT capabilities

VSATs have much in common with mobile satellite communication systems (MSAT). While MSAT terminals take telecommunication services to moving vehicles, VSATs take them direct to

fixed user premises. The VSAT terminals are not as small as MSAT terminals, thereby being capable of providing a larger range of services because the somewhat larger antenna of a VSAT allows higher data rates (bandwidths) on the up- and downlink between the VSATs and the satellite (section 3.1.4).

VSAT communication networks provide a highly efficient, traffic adaptive, high speed, low cost, bypass network offering users cost stability and control, the potential for enormous network growth and reconfiguration flexibility, much needed independence, and relatively higher immunity to the rapid changes in the telecommunications environment. Tables 7.2 and 7.3 show the salient features of the current categories of VSATs and the services and applications that can be recognized [10]. There are five categories: VSAT, VSAT(SS) (spread-spectrum), USAT (Ultra Small Aperture Terminal), TSAT (T-carrier, 1.544 Mbit/s, small aperture terminals) and TVSAT (Television Small Aperture Terminal). The VSATs(SS) and the USATs may be used for mobile communications as well, if there is a tracking arrangement on the vehicle.

Table 7.2: The features of the five categories of VSATs

	VSAT	VSAT(SS)	USAT	TSAT	TVSAT
Antenna Diameter (m)	1.2-1.8	0.6-1.2	0.3-0.5	1.2-3.5	1.8-2.4
Frequency Band	Ku	C	Ku	Ku/C	Ku/C
Outbound Information Rate (kb/s)	56-512	9.6-32	56	56-1544	-
Inbound Information Rate (kb/s)	16-128	1.2-9.6	2.4	56-1544	-
Multiple Access (Inbound)	Aloha S-Aloha, R-Aloha, DA-TDMA,	CDMA	CDMA	PA	-
Multiple Access (Outbound)	TDM	CDMA	CDMA	PA	PA
Modulation	BPSK /QPSK	DS	FH/DS	QPSK	FM
Works in conjunction	Without/ With Hub	With Hub	With Hub	Without Hub	With Hub
Protocol Support	SDLC, X.25 ASYNC,BSC	SDLC, X.25	Proprietary	-	-
Network Operation	Shared/ Dedicated	Shared/ Dedicated	Shared? Dedicated	Dedicated	Shared/ Dedicated

Table 7.3: Existing VSAT network services and some typical applications

SERVICES	APPLICATIONS
A) Broadcast & Distribution Services	
Data	Database, weather, stocks, bonds, commodities, price list, inventory, and retail sales
Image	Fax
Audio	News, program music, floor music, advertisements, and air traffic control
Video	
a)TVRO	Entertainment reception
b)Business TV (BTV)	Education, training, and information downloading services
B) Collection & Monitoring Services	
Data	Pipeline and weather
Image	Charts and ice-imagery
Video	Highly compressed surveillance images
C)Two-way Interactive Services (Star)	
Data	Credit card authorization, financial transactions, point of sale, database services, CAD/CAM, reservation, library, etc
D) Two-way Interactive Services (PT-PT)	
Data	CPU-CPU, DTE-CPU, LAN interconnect, E-mail, etc.
Voice	Thin route voice and emergency voice
Video	Compressed video teleconferencing

7.2.2 VSAT network topology

VSAT networks have been successful chiefly because they address a communications topology that appears to be ideally suited to the satellite industry - point-to-multipoint. Terrestrial networks always had trouble addressing this requirement. The fact that VSATs immediately provided equality of access and blanket coverage, coupled with their mass production, will be the key to the future use of VSATs.

Today's VSAT networks are arranged in a star configuration with all the traffic routed through a central hub, thus necessitating double hop for VSAT-to-VSAT traffic (Fig. 7.2 [11]). This means a double hop satellite delay for interactive voice applications, which may be undesirable. In table 7.2, only the TSATs can have direct access to each other. Future satellites (section 3.2.3) may overcome this problem by incorporating in their transponders the hub functions.

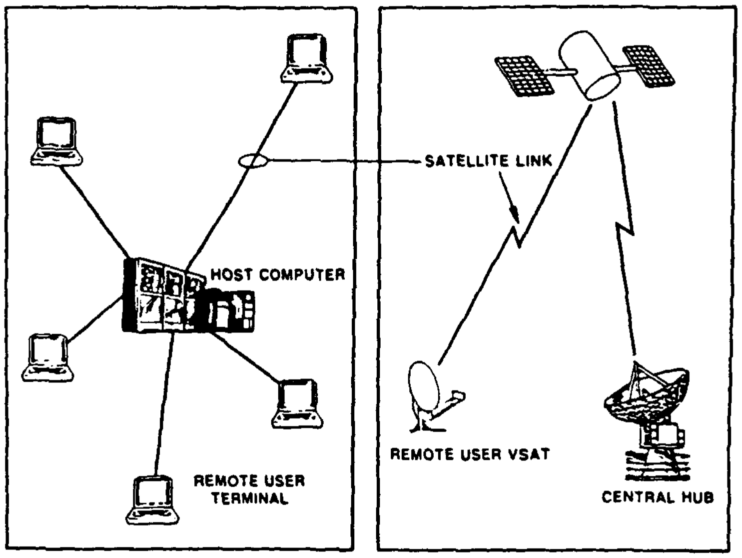

Fig. 7.2: Today's VSAT network

7.2.3 The use of VSATs

In Europe, the use of VSATs certainly lags behind that in the U.S.. There is however a significant demand for cross-national data distribution in Europe, particularly within the multi-nationals. This follows from a study commissioned by Eutelsat with CAP Scientific, London.

As far as the equipment is concerned, implementation of VSAT systems would be no problem in Europe. The frequency band used is the Ku-band. The technology is already that advanced that this band gives no difficulties. Ku-band is chosen above L-band, which was primary at first instance, because of the far greater transponder availability, the wider frequency band allocations, and lack of terrestrial interference [8]. In contrast to the use of interactive VSAT systems in the United States, the broadcast mode is likely to be the most important to European users. There are many large database system operators that are extremely interested in VSATs. The demand for high reliability in broadcast mode requires the system protocols to be verified. There have been tried several U.S. VSAT systems in Europe, as currently there are only a few known European manufacturers, but the U.S. systems currently available do not satisfy these requirements. Few

protocols have been verified and designed with fault tolerance in mind, so this remains a technological problem, along with perhaps a range of LAN interfaces.

In order to convince potential European users of the capabilities of VSAT systems, some European firms have build the first European VSAT network in a co-operative project. The central hub station is located in France while the microstations are in Athens, Hanover, Cologne, Madrid and Paris. The network was used for data broadcast and embedded in an Electronic Mail system.

While VSAT vendors are trying to improve the technology and productivity, service providers are engaged in developing new applications to exploit the full potential technology and expand the market base. In [10] three potential new applications are presented:

1. Flexible interconnecting between Local Area Networks (LANs) and Metropolitan Area Networks as well as gateway access to centralized information databases and computing services by realizing a VSAT-based Satellite Wide Area Network (SWAN)
2. The potential provision of ISDN compatible services via VSATs both in conjunction with existing satellites as well as future *Advanced Satellites (ADSAT) having on-board switching* and processing capabilities
3. The use of VSATs to solve backhaul interconnecting/internetworking problems associated with evolving Mobile Satellite (MSAT) communications networks (for example a vehicle operator who has an MSAT network to communicate with the vehicles but wishes to be able to communicate with his customers at the same time)

If the interested reader wants to get more acquainted with the subject of VSATs the references [8] and [10] to [24] are strongly recommended. In the next section advanced satellite concepts will be discussed. They will open up new possibilities for MSAT and VSAT networks.

7.3 New technologies

In the previous section it is stated that VSATs provide corporations with a cost effective method of collecting large amounts of random data from large numbers (possibly thousands) of locations. These networks, because they bypass the terrestrial system and are cost effective, are growing rapidly. However, the VSAT system is not effective in terms of voice traffic which still comprises approximately 85% of all traffic. This limitation on voice traffic is a function of the delay due to

the double hop communications. Another limitation is attributed to the amount of cost effective throughput possible. A non-processing satellite, i.e., bent pipe, cannot support the high data rate requirements desired by businesses on small terminals and be cost effective [25].

Several countries have initiated programs to develop those satellite capabilities required to make them competitive with terrestrial technologies in the next decade. The three key technologies that are being developed are: electronically hopped or scanning spot beam antenna systems, satellite-based electronic circuit switches, and intersatellite communication links, primarily laser based with data rates in the several Gbps range. Of course, these techniques could also serve the voice traffic of the international telephony links. Applying intersatellite links, bulk traffic could be supported with only one satellite hop from one point to every point on earth.

7.3.1 Spot beam antennas

Most present domestic satellites have antennas that produce only a few shaped beams that cover one or more nations. A typical antenna gain corresponding to such beams is 33 dB, dropping to 27 dB at the edge of the coverage. Replacing this antenna configuration with one that produces multiple spot beams could provide an additional gain of 10-20 dB per beam. The additional gain is limited by the difficulties in launching antennas with very large diameters. To overcome this difficulty, unfurlable antennas could be used such as applied on NASA's ATS-6 satellite [26].

In addition to the higher gain, multiple beams have the advantage of using spatial separation. By using spatial separation the same frequency band can be used in geographically separated beams, thus increasing the bandwidth availability by several fold. The beams can be geographically fixed or hopping (to reduce the required number of satellite receivers, transmitters, etc.). In a hopping system, each of M independent beams continuously hops to N different locations. A virtual pattern of MxN spots will be the result. A hopping-beam system offers the possibility to dynamically adjust the dwell time in each location depending on the demand for traffic at that location, thus optimizing the use of the system's capacity.

In Fig. 7.3 [11] on the next page the difference between a conventional and a future satellite is shown. Table 7.4 compares single and multiple beam satellites.

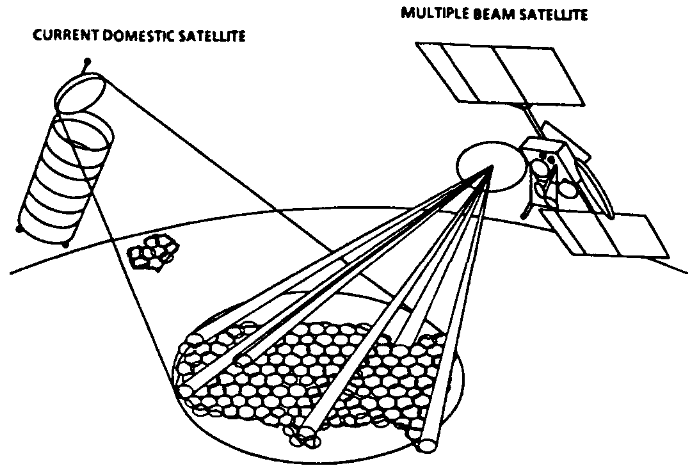

Fig. 7.3: Multiple beam satellite vs. current single beam satellite

Table 7.4: Comparison of single beam and multiple beam satellite antennas

Parameter	Conventional Single beam satellites	Future Multiple beam satellites
Power flux density	Low The energy is spread	High Focused high EIRP spot beams
Spectrum efficiency	Low Cannot reuse frequency (except by polarization)	High Spatial diversity enables frequency reuse among spot beams
Feed/antenna complexity	Simple feed	Complex feed array and beam forming networks
Payload complexity/ interconnectivity	Simple transponders	Complex onboard processing and switching to allow signal flow among beams

It is obvious that the use of hopping beams requires a TDMA access scheme, which implies more expensive groundstations. Earth stations for TDMA are always more expensive than those supporting FDMA (and providing the same bandwidth) because a higher transmit peak power for the high data rate TDMA burst is necessary (available power and data rate are very dependent on each other, which is made clear in section 3.1.4).

Producing multiple spot beams has several consequences for the satellite. The satellite antennas have to be large, there have to be complex beam forming networks, and there is a need for a routing mechanism on board the satellite.

7.3.2 Satellite-based switching

The routing mechanism on board a multiple beam satellite can be dynamic or static. Dynamic routing can be accomplished by using fast switches or by using multiplexers (FDM or TDM). Static routing can be done by using a matrix of filters and by cross strapping transponders. For next generation satellites this will be already a large improvement in respect of the bent-pipe single beam satellites of today. The flexibility of dynamic routing however offers much more possibilities. Two switching approaches can be distinguished: Intermediate Frequency (IF) switching and baseband switching. It leads to Satellite Switched TDMA (SS/TDMA) (section 2.4.3).

If the switching is baseband, the satellite is inherently a regenerative satellite. It requires demodulation/remodulation in the switching process. For VSAT network star topologies this means that functions of the central hub station are lifted on board the satellite. This implies that double satellite hops will be past time because it enables VSATs to communicate directly to each other. For voice applications this will be very practical because of the reduced time delay. An important disadvantage is however that the transmit rate will be fixed after the satellite launch.

Fig. 7.4 [27] shows an advanced communication satellite on board processing repeater. A very sophisticated technology is presented in [27], were optical technologies for signal processing in satellite repeaters are discussed.

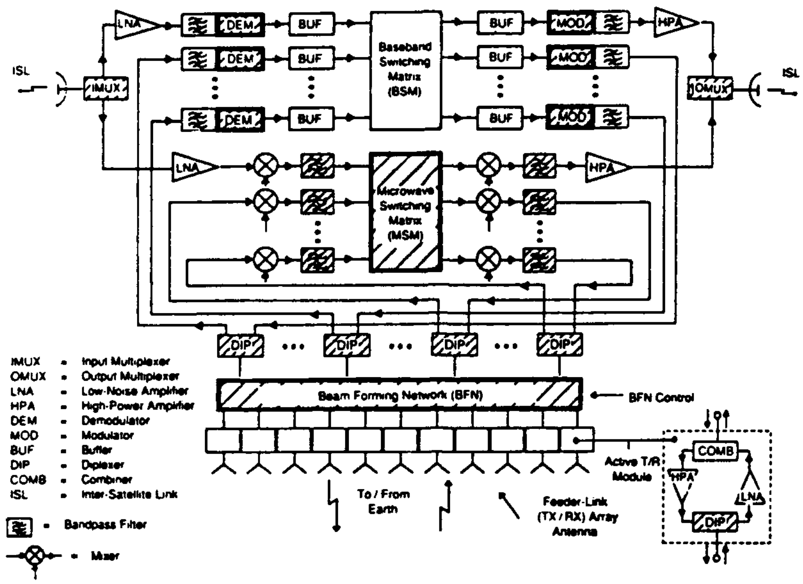

Fig. 7.4: Advanced communication satellite on board processing repeater

7.3.3 Intersatellite links

Intersatellite links can provide direct communications between satellites. Global communications will be possible without multiple hops between satellites and large trunking ground stations [28]. Intersatellite links are defined as follows [29]:

"An intersatellite link is a communications link that directly connects two separate satellites. One satellite could have several links to numerous other satellites. In some of the literature, intersatellite links (ISLs) have also been called crosslinks."

"What ISLs will do is transform communications satellites, which today are basically repeaters, into an interconnected global network in the sky. ISLs can be used to connect two separate communications satellite networks expanding the effective coverage for each system. They can be used for space vehicle communications. This will become more important as man moves deeper

into space. One of the more near term applications is in telemetry and control systems. The need for a series of earth stations around the globe to control satellites can be replaced by ISLs."

There can be distinguished two means of implementing ISLs, millimetre wave (MMW) technology and laser technology. MMW technology is of lower risk than optical ISL technology. Design issues concerning MMW technology are frequency, antenna positioning, acquisition and tracking, antenna type, power amplification, and link analysis. Frequencies are mostly above 30 GHz, allowing small directional antennas and high bitrates.

The laser technology tends to be regarded as a less mature technology than MMW ISL technology. It has a high potential though, especially for requirements of higher data rates. A high gain can be achieved with small reflectors. This allows the transmitter and receiver to be small and lightweight with low power consumption. Optical links also provide a high degree of privacy in communication and are largely immune from electrical interference. Design issues concerning laser technology are laser source, optical detector, and tracking and acquisition [30].

7.3.4 Conclusions

The experimental satellites of today (NASA's ACTS, ESA's OLYMPUS and NASDA's (National Space Development Agency of Japan) ETS-VI [31]) incorporate many of the technologies that will be important to future satellite systems and VSAT systems in particular. For experimenters in Europe the Olympus satellite is at the moment the most important one [32].

The shifting pattern of satellite usage can be summarized as follows [33]:

- telephony: the current declining rate of growth for trunking in the face of cable competition may eventually become an overall downturn, although this can be in part offset by concentration on rural telephony and services for the developing world;
- mobile satellite services: an area ripe for growth into the next century as existing maritime services are joined by aeronautic and land-mobile systems of steadily evolving complexity and coverage;
- business services: the highly lucrative VSAT revolution has been cited as the short-term saviour of the SATCOM industry - its expansion in the US continues, in Europe the explosion is only just beginning;

- TV services; full-time and occasional satellite use for TV distribution continues to expand in these TV- and channel-mad times - cable and Direct Broadcast Satellite (DBS) activity should serve to increase the importance of TV to the satellite industry.

7.4 References

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8 OVERVIEW OF MILITARY SATELLITE COMMUNICATION SYSTEMS

This chapter gives an overview of the military Air, Land and Sea SATCOM systems of the several nations. An important source of information was reference [1], chapter 5, which describes on a global level the various communication satellites developed by the U.S. Department of Defense (DoD), joint programs with Britain and the North Atlantic Treaty Organization (NATO), and the British military satellites (Skynet). The U.S.S.R. satellites are described in [1], chapter 6. References to more detailed articles, reports and conference proceedings are included in this chapter as well.

8.1 United States

8.1.1 IDCSP

The United States started military satellite communications with the launch of the IDCSP (Initial Defense Communication Satellite Program) satellite in 1966. It was a very simple repeater with no telemetry, tracking and command possibility. The single transponder had two Travelling Wave Tubes (TWTs), one on and one standby. The satellite could support three kinds of two-way circuits: up to 5 commercial quality voice, or 11 tactical quality voice, or 1550 teletype. A total of 26 IDCSP satellites have been launched from 1966 to 1968.

8.1.2 TACSAT

The IDCSP satellites however could not support tactical satellite communications, therefore DoD initiated the development of TACSAT. Although much more advanced, no flight model was assembled because of funding limitations and the qualification model was the one launched. The satellite was aimed for a complementary function of the IDCSP satellites, which could only support strategic communications between large groundstations. TACSAT was designed for operation with small land-mobile, airborne, or shipborne tactical terminals. The qualification model was used extensively for military applications, especially in the UHF range (225-400 MHz).

8.1.3 DSCS II

DoD notified that the IDCSP satellites (at that time called Phase I of the Defense Satellite Communications System (DSCS)) could fulfil certain military needs. Therefore Phase II was started with the development of the DSCS II satellites. The DSCS II satellites are significantly

different from the IDCSP satellites, but are still able to interoperate with the Phase I ground terminals. The communications payload consists of two earth coverage antennas and two narrow beam antennas. The subsystem includes preamplifiers that can be switched to various gains to allow either linear or saturated operation of each channel. The orbital locations of the satellites are the Atlantic, East Pacific, West Pacific, and Indian Ocean.

8.1.4 FLTSATCOM and AFSATCOM

After the end of life of the Tacsat experimental satellite (and also the Lincoln Experimental Satellites LES-5 and LES-6) there was a need for continuation of tactical satellite communications. Therefore the DoD developed the Gapfiller/FLTSATCOM system. FLTSATCOM serves Navy surface ships, submarines, aircraft, and shore stations. AFSATCOM serves Air Force strategic aircraft, airborne command posts, and ground terminals. The two systems share a set of four FLTSATCOM satellites in geostationary orbits. To provide coverage of the polar regions, the Air Force also has communications equipment packages on several satellites in high inclination orbits.

The FLTSATCOM satellites have three antennas: one for UHF transmissions, one for UHF reception and one for SHF transmission/reception (X-band, 7-8.4 GHz). SHF communications imply reception of the fleet broadcast uplink and transmission of a beacon. The antenna configuration supports 23 channels. Channel 1 is for X-band uplink to UHF downlink, 25 kHz bandwidth (1200bps composed of 15 teletype and one synchronization channel at 75 bps each). Channels 2-9 are 25 kHz bandwidth fleet relay channels (each channel is a 1200- or 2400-bps link). The Air Force will use channels 11-22 of 5 kHz bandwidth for narrowband communications (a single 75-bps link per channel) and channel 23 for wideband (500-kHz) communications (multiple FDMA links at 75 bps or a single higher rate link). The fleet broadcast and some Air Force narrowband uplinks can use processing receivers on board the satellite, which provides some anti-jam capability.

AFSATCOM would not be able to communicate in polar regions without some UHF packages on other DoD satellites in highly inclined orbits. In addition, AFSATCOM uses a single channel transponder with antijam improvements on DSCS III satellites.

Satellites 7 and 8 have an additional EHF communications package with a 44 GHz uplink and 20 GHz downlink. This package is called FEP (FLTSATCOM EHF Package) and is developed by

Lincoln Laboratory [2]. The FEP has facilitated the early operational test and evaluation of the Milstar (section 8.2.2) EHF/SHF terminals being developed by the Army, Navy, and Air Force. It has both earth coverage and spot beam antennas and is able to demodulate up to 32 received signals (FDMA uplinks), process them, reformat them, combine them into a single TDM data stream, and modulate them for downlink transmission. Uplink and downlink are frequency hopped. Fig. 8.1 [1] shows the complete FLTSATCOM Communication Subsystem, including the EHF package on satellites 7 and 8.

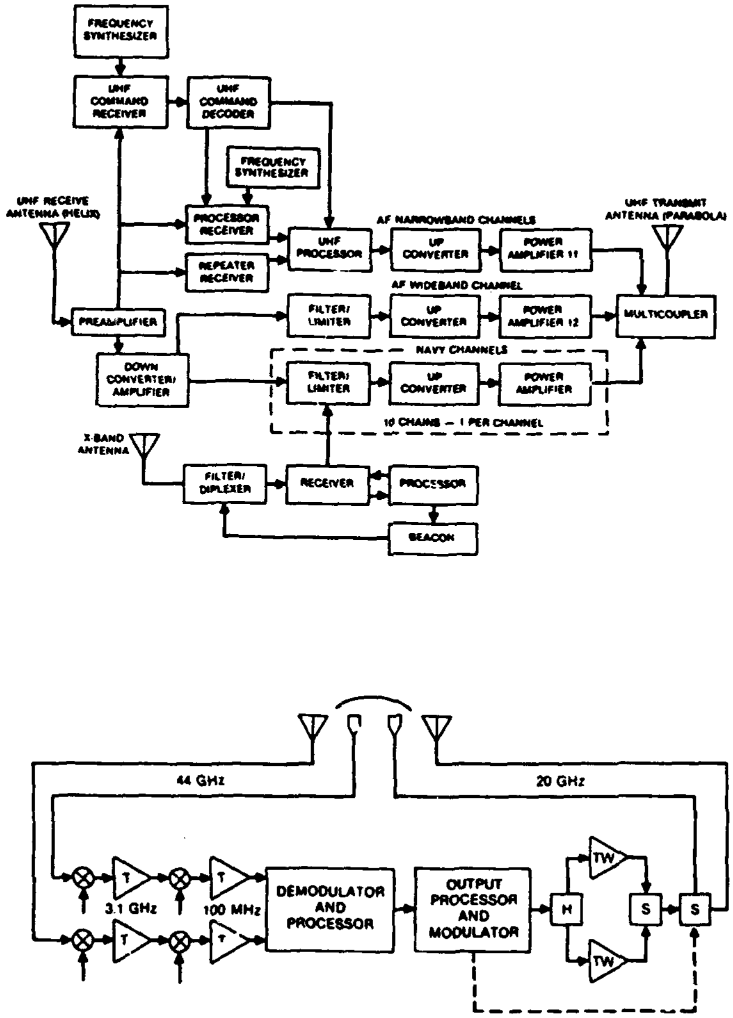

Fig. 8.1: FLTSATCOM Communication Subsystem

8.1.5 DSCS III ([3], [4], [5])

With the deployment of the DSCS III system there has been an increase in both the number and variety of terminals. While the DSCS II satellites were developed to serve long distance communications between major military locations, the DSCS III satellites were developed to operate in an environment where the majority of the DSCS terminals is small, transportable, or ship-borne.

The first DSCS III satellite is launched in 1982 and is operational at 135°W longitude. The communication subsystem has three receive and five transmit antennas that can be connected in various ways to the six transponders. Fig. 8.2 on the next page shows the DSCS III communications subsystem [1]. Each transponder can be configured to serve a specific type of user requirement. The total configuration includes the choices of receiving antenna, transmitting antenna, transponder gain level, and linear, quasilinear, or limiting mode of the preamplifiers.

There are two earth coverage and one multibeam receiving antennas. The multibeam antenna (MBA) can form any beam of arbitrary size, shape and location by means of a beam-forming network that controls the relative amplitudes and phases of each of the 61 individual beams. It can also form nulls in selected directions in order to counter jammers.

The five transmitting antennas are divided into two earth coverage antennas, two 19-beam transmit MBAs and one steerable dish antenna (parabola, 3 degrees beamwidth). The earth coverage antennas are horns, just like the earth coverage receiving antennas. The 19-beam transmit MBAs have the same capabilities as the receive MBA (except nulling) although their resolution is lower. The steerable dish antenna generates a single beam with high EIRP.

Fig. 8.2 also shows the AFSATCOM single channel transponder (SCT) that has its own UHF transmitting and receiving antennas, but can be connected to the X-band earth coverage or MBA receiving antennas. It is a regenerative transponder that demodulates the received uplink and remodulates it for transmission and that can also store messages for repeated transmission. The demodulation process provides some antijamming protection to the uplink.

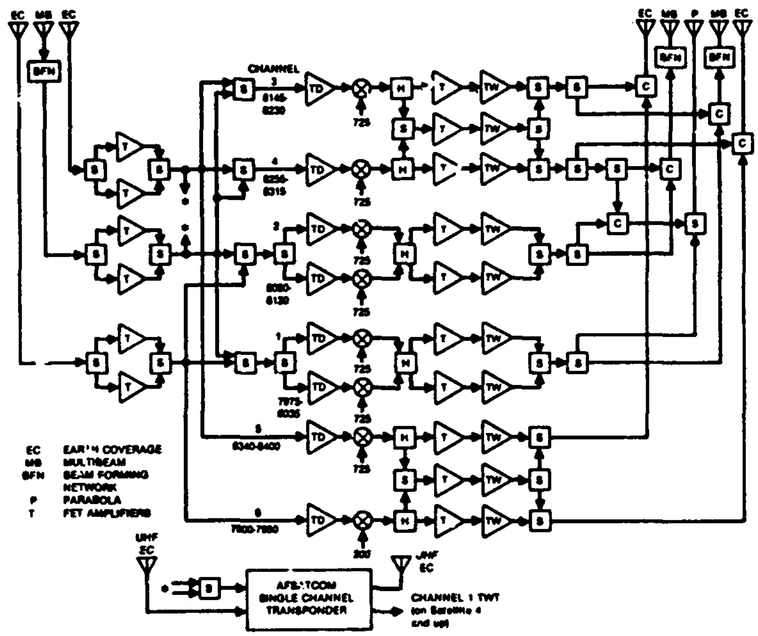

Fig. 8.2: DSCS III Communication Subsystem

The DSCS III satellite has a Telemetry, Tracking and Command (TT&C*)) subsystem which is not shown in Fig. 8.2. The TT&C subsystem operates at S-band for launch and satellite housekeeping purposes. It operates at X-band through the SHF communications payload for control of the satellite communications configuration.

It must be noted that the key feature of this satellite system is the flexible communications operation afforded by the operation of the multibeam antennas. The ability of the MBAs to provide a specialized and tailored coverage allows a communications capability consistent with anticipated NATO requirements for the fourth generation NATO communications satellite.

*) All satellites have some form of telemetry, tracking, and command subsystem to provide control and monitoring of satellite status and to obtain data from which the satellite position can be computed [1, APPENDIX D].

8.1.6 TDRSS [6]

The role of the Tracking and Data Relay Satellite system (TDRSS) is to increase the volume and frequency of communications between orbiting spacecraft and the earth. The system provides for almost continuous communications connectivity between shuttles and satellites in low-earth orbit, and their command and control elements below. The system will serve defense as well as civilian agencies.

The Tracking and Data Relay Satellites (TDRS) serve as relay platforms that receive and retransmit data produced by other spacecraft. With the TDRS, space shuttles and other spacecraft are in communication with the ground for nearly 90 percent of their flight time, compared to only 15 percent before the launch of the TDRS. The TDRSs are the largest, most complex communications spacecraft in orbit, and they can relay voice, television, digital and analog signals.

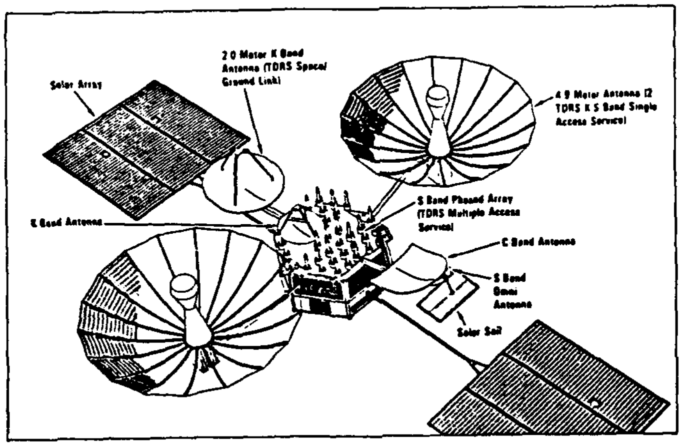

Fig. 8.3: The Tracking and Data Relay Satellite [6]

8.1.7 Navstar/GPS

Navstar Global Positioning System (GPS) is a space-based radio navigation system designed to allow an unlimited number of users to passively receive precise position, velocity and time information anywhere on or above the earth's surface [7]. A secondary mission of GPS is to detect

nuclear bursts in or above the atmosphere. The range is determined by the propagation delay of the signals from three satellites, which assumes knowlegde when they were transmitted. This timing information is calculated by using the propagation delay of the signal from a fourth satellite [8]. The satellites are in an inclined orbit that takes them over any point in their ground track approximately every 12 hours (Fig. 8.4 [8]).

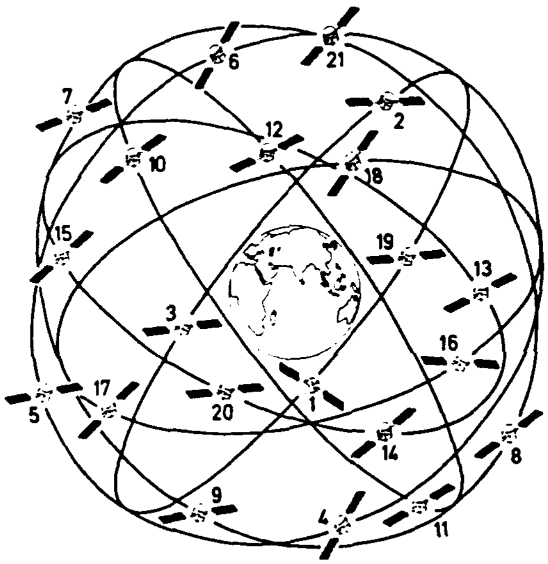

Fig. 8.4: The GPS satellites

Authorized (military) users will have access to the Precise Positioning Service (PPS), which will provide accuracies of 10 to 20 meters (95 percentile level), depending on the platform dynamics. Civilian users will have access to the Standard Positioning Service (SPS), which will provide 100 meter accuracy [9].

A technical description of the system can be found in [8]. Almost al! of the GPS satellites are placed in orbit at the moment. GPS is expected to find wide-spread use in marine, land, and air applications, since it will meet all but the most stringent navigation requirements.

8.1.8 Ground mobile forces satellite communications

The Ground Mobile Forces Satellite Communications (GMFSC) system is the Tactical satellite communications (Tacsatcom) system of the US Army. An important feature of Tacsatcom is that communications can begin within 30 minutes after arrival between command posts and individual terminals.

A typical deployment of a corps/division network consists of a single control terminal (MSQ-114) and a network of hub-spoke type arrangements as shown in Fig. 8.5 [10]. A hub-spoke type arrangement would be representative of a corps/division GMFSC network and would consist of one nodal terminal (AN/TSC-85A) and four non-nodal terminals (AN/TSC-93A).

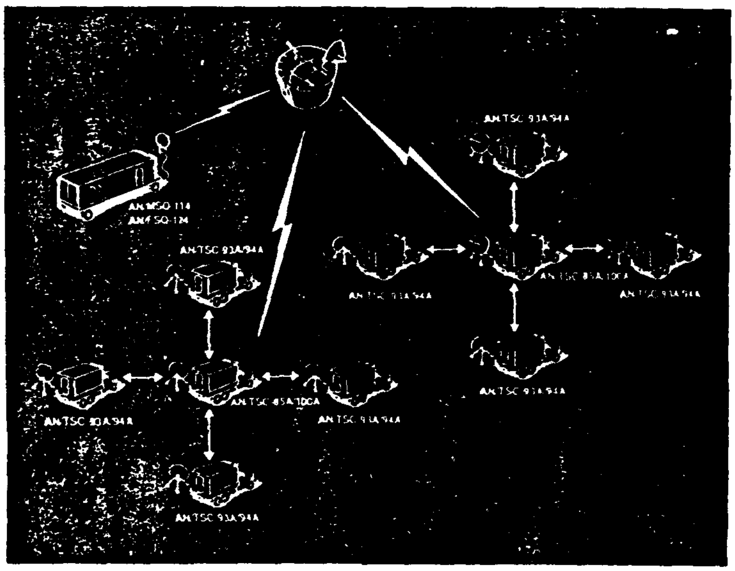

Fig. 8.5: Ground Mobile Forces tactical satellite communications network

The Ground Mobile Forces (GMF) integrated SHF antijam modems into their system to allow multichannel critical communications over extended distances and varied terrain. The SHF modems use direct sequence spread spectrum. If communications have been lost to a hostile electronic warfare jammer within the network's range, the anti-jam system responds. One by one,

each of the Ground Mobile Force (GMF) terminals can be brought back into the network through the antijam (AJ) control terminal modem. Antijam communications can be established with up to 50 terminals in a given network.

After deployment of the terminals, the Tacsatcom network will have achieved the long sought-after goal of providing a single highly mobile and flexible communications system that is suited for the battlefield environment and that provides connectivity to a range of tactical and strategic forces.

8.2 NATO

The first phase (1967) of the NATO communication satellite program was the experimental use of the United States IDCSP satellites with two ground terminals [11]. The second phase started in 1970 with the launch of the first NATO satellite, called NATO II. The UK began a parallel program with the Skynet II satellites, which were very similar to the NATO II satellites. At this moment the NATO II satellites are still in orbit but not in use anymore and the current operational satellite is NATO III.

The NATO III satellite has three communication channels with 17, 50 and 85 MHz bandwidths. The channels are received through a widebeam coverage horn antenna. It covers the North Atlantic region including the east coast of North America, all of Western Europe, and the Mediterranean. At the transmit end, the 50 MHz channel is transmitted through a widebeam path (same coverage as the receiving antenna), while the other two channels are combined in a narrowbeam path (Western Europe coverage only). The coverage patterns are shown in Fig. 8.6 [1], which also shows the location of the large static ground terminals that provide the strategic traffic connectivity.

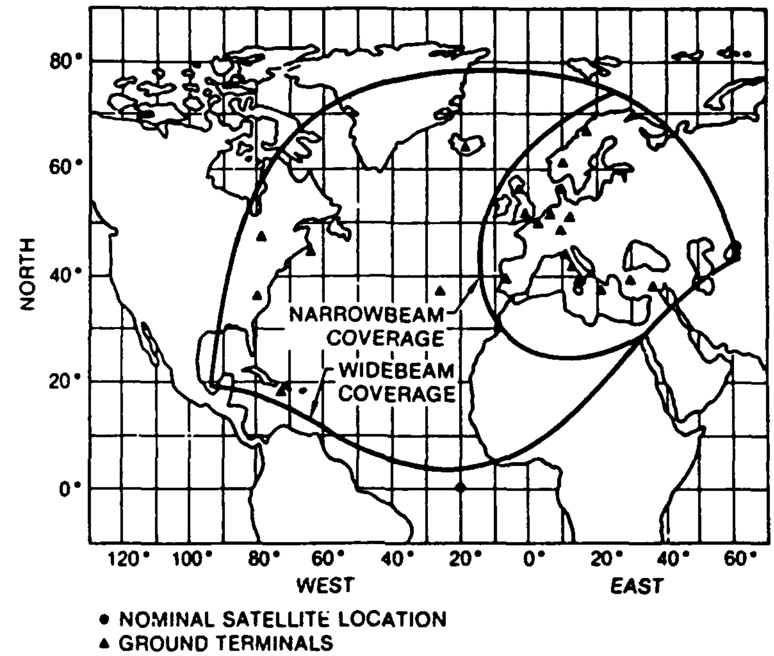

Fig. 8.6: NATO coverage and terminal locations

Most of these ground terminals, of which one is the main control centre and one is the alternate control centre, have 42 feet antennas. They provide mainly digital voice communications and share the satellite by FDMA.

Four NATO III satellites have been launched, NATO IIIA to D. At the moment NATO IIIC is providing the active role in the system. The satellite communication system is a part of the NATO Integrated Communications System (NICS), which also has various terrestrial communications links and switching and control nodes [12].

NATO IIIA is out off service at the moment. NATO IIIB will be used for experimental purposes. This satellite has also been used to serve DSCS needs until four DSCS II satellites were available. NATO IIID is kept in semi-dormant storage. It was placed in orbit because of the delay in the

NATO IV program, but it could probably remain an in-orbit spare as the NATO IV satellite will be launched at the end of 1990.

8.3 United Kingdom ([13],[14],[15])

The UK SKYNET I satellite was the world's first geostationary defense satellite (launched in November 1969). It had a single earth coverage antenna and provided 3 W output from a hard-limiting transponder. The power was divided between 2 MHz and 20 MHz channels.

The next UK military satellite, SKYNET IIB, was larger and the communications payload used a 16 W TWTA. The antenna system was again a single earth cover antenna. The satellite is still operating and used for R&D purposes.

The SKYNET III programme was cancelled on the grounds that the UK's requirement for satellite communications could be more cost-effectively met through joining the US DoD and NATO programmes. The more and more important role of small aperture, low data rate terminals for ship-borne use and tactical land use however, together with the increasing pressure on available US and NATO resources, was responsible for the decision in 1981 to start the Skynet 4 programme.

Skynet 4 is economically developed from a family of successful civil satellites (the European Communications Satellite (ECS)). The program includes two satellites and maybe a third will follow. It has a strong system resistance to all forms of electronic warfare and other military threats, achieved by hardening, nulling of unwanted signals and general signal processing.

Skynet 4 is interoperable with U.S. and NATO systems. It provides strategic/trunk links, serves multiocean maritime operations and provides comprehensive tactical communications via transportable and mobile stations [16][17][18], including individual manpacks [19][20][21][22] and, eventually, aircraft terminals [14]. A high flexibility is needed to meet this range of user requirements in terms of satellite EIRP, data rate, access schemes and resistance to jamming. It is achieved through a selection of antenna coverage, channel gain setting and detailed, flexible access planning.

The Skynet 4 satellite uses two UHF earth cover channels (250/300 MHz) and four SHF channels in the 7/8 GHz band with a total bandwidth of 340 MHz provided by three 40 W TWTAs. Two TWTAs are for the UHF channels of 25 kHz bandwidth each, giving an effective isotropic radiated power of 26 dBW. It provides a facility for experimental communications in the EHF band as well. The antenna coverage of the four SHF channels is shown in Table 8.1 [15].

Table 8.1: Some SHF frequency operating parameters

ANTENNA COVERAGE	EIRP dBW	Bandwidth MHz
Spot	39	60
Narrow	34	85
Wide	35	60
Earth	31	135

In the ground terminals of the Skynet 4 system many modern techniques are applied. The use of phased array antennas for example offer many advantages in the airborne application. The antennas can be shaped to conform to aircraft surfaces to minimise drag, and can also provide for dynamic adaptive pattern control to alleviate multipath/jamming effects and improve sidelobe performance. Substantial development work in monolithic microwave integrated circuit (MMIC) devices is being carried out to make phased array solutions a practical option for the airborne role. Minimizing the microwave devices is necessary because of the large number of integrated transmit/receive/phase-shifting elements in phased antennas and their controlling network.

8.4 USSR

8.4.1 Molniya [23]

The U.S.S.R. began to develop communication satellites early in the 1960s with the Molniya (Lightning) communication satellites used for both civilian and military communications. A total of almost 100 Molniya satellites have been launched in the well-known Molniya orbit. Very little details about these satellites are known. The first design can relay a single television signal (40 W output power) or duplex narrowband (e.g. telephone or telegraph) transmissions (14 W output power). It is not possible to determine how the design has changed during the years.

The groundstations have antennas of 40 feet in diameter. They form together the Orbita network. Apparently some functions of the Orbita network have been transferred to the Stationar satellites in recent years.

8.4.2 Stationar [24]

The Stationar satellites have a geostationary orbit. The satellites operate in the 5.7 to 6.2 GHz and 3.4 to 3.9 GHz bands. The system provides global coverage, although most of these satellites are positioned to serve the U.S.S.R. and neighbouring countries. Coverage of the U.S.S.R. requires at least two satellites. It seems that the Stationar satellites are used for civilian purposes. The three different kinds of Stationar satellites are called Raduga, Ekran and Gorizont.

8.4.3 Other satellites

The Soviet satellite program is vast. A large fraction is directly related to military objectives. The Soviets pay more attention to the amount of spacecraft in orbit, whereas the Western bodies have technologically very advanced satellites. However, the Soviet satellite is becoming more advanced too.

A four-satellite geosynchronous Gals system uses the 7-8 GHz band. They have ten narrowband channels, with three or four receivers and transmitters. Antenna patterns include earth coverage, northern hemisphere, and a spot beam with about 5 degrees beamwidth.

The Soviets have also a satellite for mobile communications (Volna). The two channel L-band equipment are for aeronautic service and for maritime service. The land mobile force is served by a UHF channel.

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9 THE FUTURE OF MILITARY SATELLITE COMMUNICATIONS

9.1 Shortcomings of the current satellite communication system

Although the military satellite service can provide communications for strategic traffic between fixed earth stations, the military mobile satellite service is very limited in its capacity at the moment.

For example, the US UHF system cannot provide simultaneous communications on different channels for a large number of users. This can be explained by the following link budget calculation for the downlink from a military UHF satellite (FLTSATCOM) to a small UHF earth station [1].

Table 9.1: Link budget calculation of the downlink from a US maritime satellite (frequency is 240 MHz)

Radiated power by satellite (e.i.r.p)	e.i.r.p.	26.0	dBW
Free-space path loss (L)	+L	-172.8	dB
Receiver antenna gain (G)	+G	+0.0	dB
Receiver noise temperature (T)	-T	-30.8	dB
Boltzmann's constant (k)	-k	+228.6	dBW/K·Hz
Fade margin (M)	-M	-4.0	dB
Required energy per bit-to-noise density for an error rate of 10^{-5} (E_b/N_o)	$-E_b/N_o$	-10.0	dB
Available data rate (R)	R	37.0	dB·sec^{-1}

The data rate R is equal to 5 kbits/sec ($10^{37.0/10}$). This is barely enough to support two vocoded voice channels (A vocoded voice channel is produced by means of a special "vocoder" which produces 2400 bits/sec digital voice. The intelligibility of such a signal is good, but the person who speaks cannot easily be recognized from his voice). Telex messages are therefore the bulk of

traffic since they only require a capacity of 75 bits/sec. For transmissions to the total of more than thousand UHF-terminals the broadcast mode can be used, while the terminals can report back by a time division multiple access (TDMA) scheme.

The limited capacity is not the only drawback of UHF communications. The jamming protection is marginal because the UHF terminals have modest e.i.r.p. and limited bandwidth available for spread-spectrum techniques. Narrow beams can only be achieved with very large antennas at UHF, so for small terminals the beamwidths are very wide and therefore UHF communications can easily be detected. High-altitude nuclear explosions can cause long periods of outage, resulting from absorption and scintillation effects. The periods of outage are proportional to the frequency, so better performance can be expected at SHF or EHF frequencies [2].

The SHF system provides significantly more capability in the above mentioned areas at low to medium data rates. The available bandwidth at the 7-8 GHz band is large in respect to the military UHF frequencies (225-400 MHz). The e.i.r.p. is much larger because the antenna gain is proportional to the square of the frequency. For the downlink it will improve the antenna gain by $10\log(7\text{GHz}/240\text{MHz})^2 = 30$ dB which means a factor thousand increase of available bandwidth if the receiver size and noise temperature is the same as in UHF (in fact the noise temperature will be much lower because of the narrower beam, causing less influence from ground noise, see section 3.1.3.1 of this report).

The satellites for SHF communication however are mainly used for strategic traffic. If the military community wanted to make full use of the capabilities of satellite communications, there would be a need for a dedicated mobile communication satellite. In the near future some new satellite systems are expected. They will enhance the capacity and survivability of the current systems and therefore the capability to support mobile communications, although they are not dedicated mobile communication satellites. NATO will enhance its capacity and survivability to that of the US DSCS III system and the UK Skynet 4 system with the NATO IV satellite, while the US is developing an extremely survivable satellite system named Milstar.

9.2 Future developments

9.2.1 Transition to mobile communications with NATO I√

In the NATO IV time-frame we will see the use of a greater amount of small ground terminals which are transportable or mobile. Current areas of research are therefore concentrated on minimizing the size of the elements of the ground stations. Areas of interest are:

- hybrid solid state power amplifiers (with respect to TWTs, they are lightweight and reliable).
- Microwave Monolithic Integrated Circuits (MMIC's), to provide militarized Low Noise Amplifiers (LNAs), mixers and oscillators.
- phased array antennas.
- modem equipment (capable to cope with doppler effects and to acquire fast acquisition while providing anti-jam resistance).
- Demand Assignment Multiple Access (DAMA) protocols for multiple users and low data rate (several hundreds of bps).

Reference is made to the publications of the Royal Signals and Radar Establishment (RSRE) research projects on portable and manpack terminals [3]-[11].

9.2.2 Future U.S. military strategy

The U.S. military strategy is in a transition period at the moment. The emphasis will be on attaining a more balanced military capability to deal with a wider range of contingencies across the spectrum of conflict, and satellite communications systems (with Milstar at the forefront) will be a major ingredient of this new realignment. It will provide more flexible and interoperable capabilities which are required by lower intensity conflicts.

Milstar will operate in the extremely high frequency (EHF) band. Several options exists to extending this EHF service to low intensity conflict [12]:

- development of small, portable EHF terminals compatible with existing and planned space segments
- extension of the Milstar architecture by adding compatible EHF transponders on other host satellites
- evolution toward a more integrated satellite architecture based on Milstar concepts and technology.

9.2.3 Optical satellite communications

Optical satellite communications are very interesting for military satellite communications. These could be used for intersatellite links and space-to-ground communications [13]. The benefits of optical satellite communications would be a very good Low Probability of Exploitation (LPE) by adversaries, through the very narrow beamwidths, small antenna apertures, wide bandwidth capability, and potentially good jamming resistance.

It has also been suggested that the use of blue-green light may permit communication to submarines below the sea surface. A Submarine Laser Communications (SLC) system would represent the most complex communications system known to man. The operational value would be very large: a transmitted laser signal from a satellite is able to penetrate sea water to depths of hundreds of feet. The optical link enables a high data rate. These two facts make SLC very attractive as a submarine command and control link. With this capability, submarines are allowed to operate at optimum depth and speed [14].

9.3 Future satellite systems

9.3.1 NATO SATCOM Phase IV

NATO recently decided to place into orbit a new family of two satellites designated as NATO IV. The programme is carried out in co-operation with the UK, because for NATO IV the UK Skynet 4 design was selected. The satellites were originally planned for the 1987-97 time-frame, but the first launch has been postponed to 1990 [15].

The antenna coverage has slightly changed with respect to Skynet 4 to fulfil specific NATO needs. The coverage is more Europe oriented with respect to the UK Skynet 4 satellite. It does not contain the EHF package of Skynet.

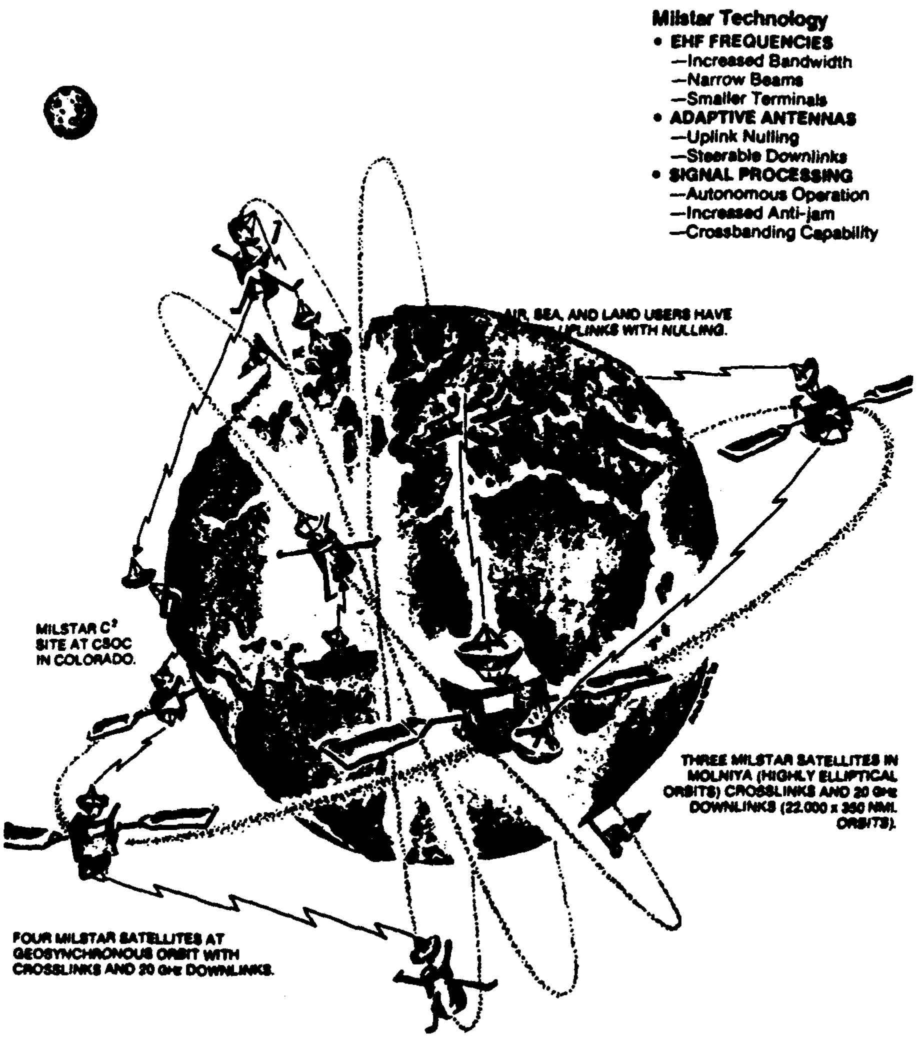
Like Skynet 4 the satellite will be hardened against the effects of nuclear detonations in space. As such the satellite was designed to survive system-generated electromagnetic puls (EMP) and high doses of radiation. It will have features to counter the effects of enemy jamming (antenna nulling and signal processing). It is capable of supporting both strategic and tactical communication links through the much more sophisticated transponder with respect to the NATO III transponder (more power, more bandwidth and more downlink beams including earth coverage and spot beams).

9.2.2 Milstar

In the early 1980s a major system improvement was planned by the US DoD for the 1990s. This resulted into the Milstar (MILitary Strategic/TActical and Relay) system, which is now being prepared for deployment [16].

Milstar will provide both tactical and strategic service for mobile users. The space assets will be in both low and high inclination orbits (fig. 9.1 [17]). As such it enables a global coverage without single vulnerable nodes. Intersatellite links at 60 GHz will provide network flexibility. As the earth's atmosphere is effectively opaque to transmissions at 60 GHz, these links cannot be jammed by large ground stations, nor can they be intercepted. Milstar provides EHF and UHF communications. The EHF uplink frequency is 44 GHz and the downlink frequency is 20 GHz which is in fact in the SHF band.

The UHF communications payload is for compatibility with the approximately 1200 currently deployed UHF terminals. For broadcast applications the UHF-band can very well be used in combination with the EHF-band. For this application the EHF-band can best be used on the uplink, which is under the most serious threat, because an EHF uplink can very well be protected by a wideband spread-spectrum waveform. The antenna systems of most satellites face hostile territory and uplink jamming is therefore possible by means of a large ground station, while downlink jamming requires the adversary to approach very close to the ground stations. In the satellite, the waveform is demodulated and despread, before remodulating it on a UHF downlink where the bandwidth is too small for spread spectrum techniques.



Global, secure, and highly jam resistant communications will be achieved by orbiting four Milstar satellites at geosynchronous (22,300 nm) and three in highly elliptical (Molniya) polar orbits. Satellites will have orbital crosslinks and advanced survivability capabilities. Milstar will have 44 GHz uplinks with 20 GHz satellite downlinks to some 4,000 receiver terminals by the early 1990's. The Milstar mission control station will be at the USAF Space Command Consolidated Space Operations Center, CO.

Fig. 9.1: A MILSTAR communications concept

Milstar will use the EHF band for the following reasons [18]: EHF can overcome frequency-congestion difficulties for unprotected communication links. For jam-protected links EHF supplies the bandwidths necessary to implement robust, anti-jam systems based on spread-spectrum technologies. Because the antenna gain rises proportional with the square of the frequency, small antennas can be used which implies a modest-sized satellite. The narrow beam gives a low probability of intercepted transmissions from terminals that wish to remain unnoticed.

EHF has also some disadvantages. The most important ones are the effects of rain attenuation on link operation at EHF which require that - to minimize outage - the minimum elevation angle of the satellite relative to the terminal must be significantly higher than for lower-frequency systems. Milstar uses therefore high inclination orbits, next to the geostationary ones, to extend the coverage to the polar regions.

Milstar is designed from start to finish as a warfighting system. Major development efforts include: reliable, "low-risk" travelling wave tube amplifiers, fault tolerant spaceborne computers, advanced adaptive antennas, nulling antennas, hardened electronics and high-speed processors, protection from physical attack (including nuclear hardening), "low cost" small EHF terminals (terminal antennas will be in dish configurations and range in size from about 1 ft. to 5 ft. in diameter), low-noise amplifiers and high-speed LSI circuits that can provide the terminals with 44 GHz uplink nulling on jammers [17].

The system's design stresses survivability over capacity. Milstar will handle only 1 megabit of data per second, and no more than 15 users will be able to simultaneously access each satellite. The system is virtually unjammable through the use of frequency division multiple access uplinks with frequency hopping over the entire bandwidth of 1GHz. The satellites are not only placed in high supersynchronous orbits to provide hemispherical line-of-sight, but also to provide a degree of protection from anti-satellite weapons, which are nominally designed to destroy satellites in low to medium orbits [19]. A high degree of flexibility is reached by steerable downlink antennas and the ability to handle traffic multiplexed by time-division multiplexing and frequency-division multiplexing methods. Milstar will prove its value in times of war or international crisis. It will supplement rather than replace existing DoD communications satellites [20].

9.2.3 Lightsat

Lightsat is a program to develop inexpensive, lightweight satellites. A theoretical application of lightweight satellite technology is: Multichannel EHF communications, which means that Lightsats compatible with Milstar communications satellite ground elements could supplement or replace a damaged Milstar constellation. Lightsats could provide "crisis augmentation" and a "surge capability" to reconstitute critical functions if anti-satellite weapons would be used against the existing constellations of large, expensive satellites.

Because only three of the 10 Milstar satellites initially planned have been funded, it is hoped by some that Lightsats might fill the void. The future for Lightsat however is far from certain due to fluctuating funding and a vulnerability to budget cuts [21].

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10 COMPARISON OF CIVIL AND MILITARY SATCOM SYSTEMS

In civil systems all kinds of communications can be recognized, but the bulk of the traffic is generated in the international trunk circuits to support voice communications, and television broadcasts requiring approximately 30 MHz of bandwidth (5 MHz video signal FM modulated).

Military satellite communications are generally longe-range systems that frequently involve links between deployed forces and the continent [1]. For these systems light, transportable terminals are necessary that provide: coverage, rapid deployment, mobility, and physical and electronic survivability. To ensure continuous coverage for bombers and submarines operating near the North Pole, also highly elliptical orbits are used where geosynchronous satellites would be below the horizon [2]. These properties are needed during low intensity conflicts. When a full-scale conflict occurs the terminals and the satellites have to operate in a nuclear environment.

10.1 Threats and countermeasures

Military satellite communications are mainly distinguished from civil systems by the need for survivability under threat. Physical threats, like explosives and high-powered lasers [3] are fairly obvious. In military systems, as much as possible redundancy is provided. It is thought to be more effective to use a lot of small, inexpensive terminals than only a few, physically protected, expensive ground stations. Only the large anchor ground stations (supporting the telemetry, tracking and command of the satellite, the higher capacity strategic links, and the traffic handling to mobile earth stations) are hardened against EMP and physical attacks. Diversification of the large anchor stations is desirable.

10.1.1 Nuclear threat

Nuclear weapons pose special threats. They could destroy complete ground stations or satellites, but also cause dangerous radiation, electromagnetic pulse (EMP), and atmospheric ionisation (has severe influence on propagation characteristics).

Protection against radiation or EMP is called 'hardening' of the satellite. The influence of atmospheric ionisation on propagation characteristics can be countered by using higher frequencies. The periods of outage in a nuclear environment are about 2.5 times shorter at 20 GHz than at 8 GHz [4]. The currently developed military system Milstar therefore uses these high

frequencies (44 GHz uplink and 20 GHz downlink). Higher frequencies also provide a larger available bandwidth and smaller beamwidths, providing a low probability of intercept (LPI) of the ground station by an enemy [5]. A low probability of intercept is essential in preserving the ground stations from any attack.

10.1.2 Jamming

Another threat to a military communications system is jamming. Jamming may be either exploited on the uplink or the downlink. Uplink jamming is considered to be a serious threat, as most satellite receive antennas view hostile territory. Because the telemetry and command system is vital to the housekeeping and the positioning of the satellite, the TT&C uplink is the first communications link to be protected. Jammers can be countered by **antenna nulling** and **spread-spectrum techniques**.

One way to realize **antenna nulling** is shown in fig. 10.1 [6], where the output from a spot-beam antenna is subtracted from that of an earth cover antenna with a wide beamwidth. This technique is fundamentally similar to that of the interferometer, where a signal is received by two identical antennas, whose outputs are subtracted after imposition of a phase shift.

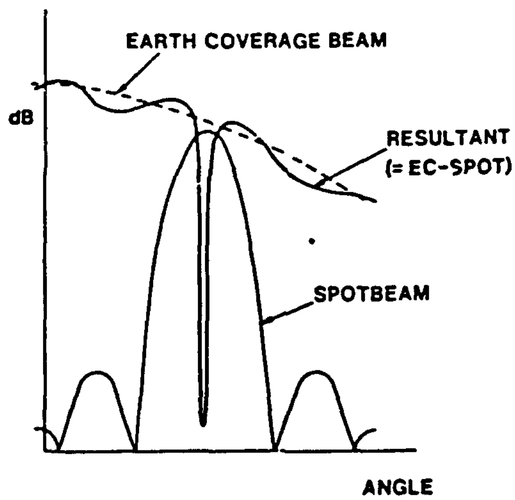

Fig. 10.1: Illustration of antenna null realisation

Spread spectrum techniques rely on the user spreading his signal with a spreading function which cannot be replicated by an enemy. Through the despreading operation at the receiver any uncorrelated interference such as jamming is spread, and the bulk of it is removed by the filter. The amount by which the carrier-to-interference ratio has increased by this process is called the processing gain. The concept is illustrated in fig. 10.2 [6].

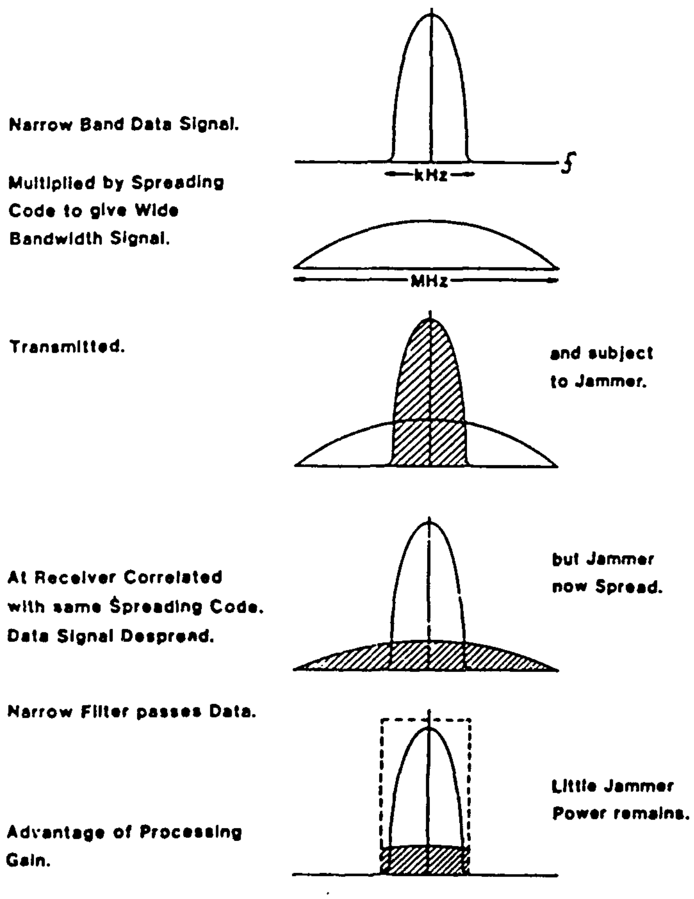

Fig. 10.2: Jamming protection through spread spectrum

The two basic spread spectrum techniques are direct sequence and frequency hopping. The direct sequence technique is explained in section 3.4.3.2, in the discussion on CDMA. Frequency hopping requires the carrier frequency to jump in discrete hops over a wide bandwidth; the receiver recovers the signal by hopping its local oscillator in synchronism. The advantages and disadvantages of these both spread spectrum techniques are described extensively in [7]. Hybrid forms of direct sequence and frequency hopping are also possible and will combine the advantages of both systems.

10.2 Comparison of the Intelsat V and the DSCS III satellite

To compare the civil and military satellite communications it is illustrative to consider a recent civil and a recent military satellite of approximately equal weight and size. Two satellites, namely the Intelsat V (commercial) and the DSCS III (military) satellite have a weight of 2200 lb resp. 2475 lb and are both 3-axis stabilized, which in general means stabilization in pitch, roll and yaw through thrusters or spinning wheels. The Intelsat V has a rectangular body of 5,4x5,8x6,6 ft and the rectangular body of DSCS III is 6x6x7 ft. The configuration of the communications channels is tabled below [8].

Table 10.1: Channel configuration of Intelsat V and DSCS III

Intelsat V		DSCS III	
6/4 GHz:	21 single conversion repeaters with bandwidths of 36 to 77 MHz, dual beam and dual polarization frequency reuse	Six channels:	85-MHz bandwidth (channel 3), 50-MHz bandwidth (channel 6), 60-MHz bandwidth (channels 1, 2, 4, 5)
14/11 GHz:	6 double conversion repeaters with bandwidths of 72 to 241 MHz, dual beam frequency reuse		

Since the power of the TWTs of Intelsat V has to be divided between a lot of channels, 21 channels at 6/4 GHz, the transmitted EIRP per channel is low with respect to that of the DSCS III satellite. The strongest 6/4 GHz channel on Intelsat V has an e.i.r.p. of 29 dBW. In contrast, DSCS III has TWTAs of 40 Watts available for channel 1 and 2 and a high gain multiple beam antenna as well as a steerable dish antenna which provide channel 1 and 2 with 40 dBW (multibeam antenna) and 44 dBW (dish antenna).

The 14/11 GHz channels on Intelsat V which are for television transmissions also have a high e.i.r.p of 41.1 dBW for the west spot and 44.4 dBW for the east spot antennas (see Fig. 6.1 for the coverage patterns). The TWTA has only 10 Watts available (6 dB less than the 40 Watts of DSCS III), but dish antennas that have about the size of the DSCS III steerable dish antenna have a 4 dB higher gain at 11 GHz than at the military downlink frequency of 7 GHz.

The different values of e.i.r.p have direct consequences for the earth terminals and applications. The Intelsat V 6/4 GHz band supports mainly the international voice-traffic on point-to-point links between large earth stations of 10 to 30 metres. Its nominal capacity is 12.000 two way voice circuits. By means of the 14/11 GHz band it can support two television transmissions. The satellite is also capable to provide low data rate services to fixed small users (business services). It is not tailored to support communications to very small mobile earth stations at 6/4 GHz. This could however be accomplished by the maritime communications subsystem at L-band frequencies, 1.5/1.6 GHz, on the Intelsat VM satellite (not mentioned in table 5.1, since it is a subsystem specifically leased to Inmarsat) and the new Inmarsat standard C ground station.

The military DSCS III satellite is able to support all types of communications in one frequency band (7.25-8.4 GHz). Even communications with portable earth stations are possible. Military communications however suffer from capacity problems. The reuse of frequencies by means of an antenna system with two orthogonal polarizations is not possible, because of the different signal strengths coming from the ground terminals. Isolations between orthoganal polarizations of about 30 dB can be achieved, but the differences between signal strengths from small and large terminals can be larger. A further reduction of capacity is caused by the need for electronic counter counter measures (ECCM) techniques to reduce the effects of jamming. The spread-spectrum techniques used for this purpose require a lot of bandwidth.

Further differences between the satellites are found in the antenna system. The hemisphere beam antennas of Intelsat V have 88-horn feeds. With such feeds the antenna pattern can be changed by switching the right horns on or off. They are necessary to be able to adapt the hemisphere beams according to the regions they have to cover at both sides of the Atlantic or Indian Ocean (see Fig. 6.1).

The DSCS III satellite also has multibeam antennas, one multibeam receiving antenna with a 61-horn feed and two multibeam transmitting antennas with 19-horn feeds. The beams shapes can be **dynamically adjusted** by electronic control of the relative amplitudes and phases of each of the 61 (or 19) individual beams. The receiving antenna can even generate nulls in selected directions in order to degrade the effects of jammers.

The DSCS III satellite system is therefore very flexible: it can adapt to reconfiguration of the ground terminals/network by changing the coverage, it can support mobile communications and provides electronic survivability. Of course the satellite is hardened, to provide physical survivability as well.

A closing comparative statement can be made as follows: the military satellite offers a high degree of flexibility and survivability, while the civil satellite offers much capacity on fixed communications links. In respect to the flexibility aspect of civil satellite systems this statement is becoming untrue for modern and future satellite systems. The flexibility that SATCOM systems can provide will be the right to exist for future civil satellite systems.

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11 CONCLUSIONS

Through the study of satellite communication systems and the investigation on the future developments an insight on satellite communications is obtained which has led to the following conclusions:

General

- Satellite communication systems can provide the benefits of global coverage, flexibility, mobility, communication to low density population areas, provision of private networks, and heavy trunk connections.

- During the first decades the systems were not developed to a stage in which land mobile and aeronautic satellite communication systems would be efficient in terms of size and cost. But now the emphasis in both civil and military satellite communication will be more on mobility and flexibility, because fibre optics will decrease the need for fixed high capacity satellite links like the international point-to-point trunks for telephony and telegraph.

Civil satellite communications

- With respect to land mobile satellite communications in Europe there is expected a market for specific applications that cannot be served by the terrestrial networks adequately, such as private mobile communications networks for truck companies.

- At the moment land mobile and aeronautic satellite communication systems still are an emerging technology. Recent improvements however in transmitting, receiving and modem equipments have led to a reduction of the size of the earth stations, while cheaper components enable a lower price. In the United States this has already brought forth the exploitation of very small aperture terminal (VSAT) systems with earth station antennas of about 1 m in diametre. The earth stations can easily be installed and are transportable.

- VSAT networks are a very good solution for applications, where cost stability and control, the potential for enormous network growth and reconfiguration flexibility, and independance are important benefits. VSATs are able to provide point-to-multipoint connections (e.g.

broadcasting for data gathering purposes) very easily whereas this always has been a problem for terrestrial networks.

- In VSAT-networks the star-network concept is used wherein the VSATs communicate with a relatively large central "hub" earth station. Point-to-point connections between VSATs are only possible for low data rates because of the limited antenna gain and power of the satellites of today. For communications between VSATs therefore a double hop through the satellite via the hub is necessary. Three new key technologies which are in an experimental stage could solve this non-effectiveness in providing voice communications and limited amount of cost effective throughput possible of VSATs; electronically hopped or scanning spot beam antenna systems, satellite-based electronic circuit switches, and intersatellite communication links.

Military satellite communications

- The military requirements impose specific requirements to the military communications satellite. Survivability to potential threats like physical attacks (by providing redundancy), dangerous radiation caused by nuclear weapons (by "hardening" the satellite) and jamming (by employing spread-spectrum techniques and antenna nulling) is a prime requirement. A military communications satellite has to be very flexible because it has to handle a variety of different earth stations over a wide area. The earth stations can be different in power, traffic and modulation scheme and they can be mobile, transportable or fixed.

- UHF-SATCOM is very limited in its survivability and capacity and therefore there is a need for small and transportable/mobile ground terminals at SHF or EHF. These frequency bands, especially the EHF band, are much more suited to overcome frequency congestion of unprotected links and to provide a low probability of signal interception and resistance to jamming.

- Optical satellite communications techniques could meet the military requirements even better. They could permit virtually unjammable communication, a very high information transfer rate between satellites and reduce the dependence of vulnerable ground relays. Optical communications techniques are however in an experimental stage.

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LIST OF ABBREVIATIONS

ACTS	Advanced Communications Technology Satellite
ADPCM	Adaptive Differential Pulse Code Modulation
ADSAT	Advanced Satellites
AFSATCOM	Air Force Satellite Communication
BSS	Broadcasting-Satellite Service
CDMA	Code Division Multiple Access
CES	Coast Earth Stations
DAMA	Demand Assignment Multiple Access
DBS	Direct Broadcasting Satellite
DCME	Digital Circuit Multiplication Equipment
DM	Delta Modulation
DoD	Department of Defense (of the United States)
DSCS	Defense Satellite Communications System
e.i.r.p. and EIRP	Equivalent Isotropically Radiated Power
ECCM	*Electronic Counter-Counter Measures*
ECS	European Communications Satellite
EHF	Extremely High Frequency
EMP	Electromagnetic Puls
EPIRBs	Emergency Position Indicating Radio Beacons
ESA	European Space Agency
ETS	Experimental Test Satellite
FDM	Frequency Division Multiplexing
FDMA	Frequency Division Multiple Access
FEP	FLTSATCOM EHF Package
FET	Field Effect Transistor
FLTSATCOM	Fleet Satellite Communication
FSS	Fixed-Satellite Service
G/T	the figure of merit, which is the receiving antenna gain divided by the noise temperature of the receiving system
GaAs	Gallium Arsenide
GMF	Ground Mobile Forces

GMFSC	Ground Mobile Forces Satellite Communications
GPS	Global Positioning System
HPA	High Power Amplifier
IBS	Intelsat Business Service
IDCSP	Initial Defense Communication Satellite Program
Inmarsat	International Maritime Satellite Organisation
Intelsat	International Telecommunications Satellite organization
ISLs	Intersatellite links
ISS	Intersatellite Service
ITU	International Telecommunication Union
LAN	Local Area Network
LNA	Low Noise Amplifier
LOS	Line Of Sight
LPE	Low Probability of Exploitation
LPI	Low Probability of Intercept
MBA	Multibeam Antenna
MCPC	Multiple Channel Per Carrier
MCS	Maritime Communications Sub-systems
MILSTAR	MILitary Stategic/Tactical and Relay
MMIC	Monolithic Microwave Integrated Circuit
MMW	Millimetre Wave
MSAT	Mobile Satellite
MSS	Mobile-Satellite Service
NASA	National Aeronautics and Space Administration (of the United States)
NASDA	National Space Development Agency (of Japan)
NATO	North Atlantic Treaty Organisation
NIC	Nearly Instantaneous Companding
NICS	NATO Integrated Communications System
NOC	network Operations Centre
NPR	Noise Power Ratio
PCM	Pulse Code Modulation
pfd	power flux density

PPS	Precise Positioning Service
PSK	Phase Shift Keying
RARCs	Regional Administrative Radio Conferences
RF	Radio Frequency
RNLN	Royal Netherlands Navy
SATCOM	Satellite Communication
SCF	Satellite Control Facility
SCPC	Single Channel Per Carrier
SES	Ship Earth Stations
SES	Société Européenne de Satellites
SHF	Super High Frequency
SLC	Submarine Laser Communications
SMS	Satellite Multi-service System
SOC	Satellite Operations Centre
SPS	Standard Positioning Service
SS/TDMA	Satellite Switched Time Division Multiple Access
SSB-SC	Single Sideband Suppressed Carrier
SWAN	Satellite Wide Area Network
TACSAT	Tactical Satellite
TACSATCOM	Tactical Satellite Communications
TDM	Time Division Multiplexing
TDMA	Time Division Multiple Access
TDRSS	Tracking and Data Relay Satellite System
TSAT	T-carrier Small Aperture Terminal
TT&C	Telemetry, Tracking and Command
TVRO	Television Receive Only
TVSAT	Television Small Aperture Terminal
TWTA	Travelling Wave Tube Amplifier
UHF	Ultra High Frequency
USAT	Ultra Small Aperture Terminal
VSAT	Very Small Aperture Terminal
VSAT(SS)	Spread-spectrum VSAT
WARCs	World Administrative Radio Conferences

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THE PROJECT A90KM616, "ORIENTATIE SATCOM", IS BEING PERFORMED ON BEHALF OF THE ROYAL NETHERLANDS NAVY (RNLN) TO ASSIST THE NAVY IN THE AREA OF SATELLITE COMMUNICATION. THIS REPORT IS THE RESULT OF THE FIRST PHASE OF THIS STUDY. THE SCOPE OF THE REPORT IS TO GIVE AN OVERVIEW OF THE PHENOMENON SATELLITE-COMMUNICATION.

THE RESULT OF THE STUDY IS A GENERAL INSIGHT IN SATELLITE COMMUNICATIONS FOR BOTH CIVIL AND MILITARY APPLICATIONS. SOME EXAMPLES OF APPLICATIONS ARE; INTERNATIONAL TELEPHONY, TELEVISION BROADCASTING, SMALL PRIVATE BUSINESS NETWORKS, AND MOBILE (AT THE MOMENT STILL PRINCIPALLY MARITIME) COMMUNICATIONS. IN THESE APPLICATIONS SATELLITE COMMUNICATION SYSTEMS PROVIDE A GLOBAL COVERAGE AND A HIGH FLEXIBILITY.

THE SCIENTIFIC ARTICLES HAVE NOT BEEN CONSIDERED BECAUSE IN THIS STAGE IT WAS NOT THE INTENTION TO STUDY THE BROAD AREA OF TECHNIQUES ON A SPECIALIST LEVEL. MAGAZINES, BOOKS AND A NUMBER OF REPORTS OF UNIVERSITIES AND RESEARCH INSTITUTES HAVE BEEN THE MAIN SOURCES OF INFORMATION. THEY AFFORDED AN UNDERSTANDING OF THE EXISTING SYSTEMS AND AN INSIGHT IN THE FUTURE DEVELOPMENTS.

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